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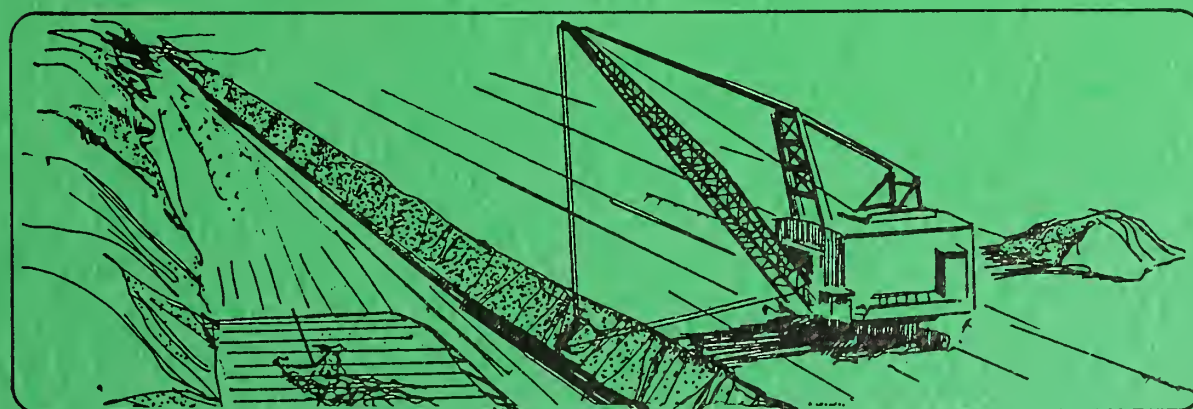
Proceeding Of The 8th Annual National Abandoned Mine Lands Conference



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I N T R O D U C T I O N

During the week of August 11 through August 15, 1986 the State of Montana hosted the Eighth Annual National Abandoned Mine Lands Conference in Billings, Montana. The conference provides professional interaction and presents technical advancements made to reclaim abandoned mines in the country.

In previous years, technical papers presented at conferences were not published. In many cases, worthwhile information was lost by not having a printed record. Our goal with this publication is to provide a permanent record of the papers presented at our conference.

All the papers that were submitted to the Department at the conference are published in this proceedings. Each paper has been retyped as they were submitted by the author. No editorial changes have been made. For further information the reader may contact the author.

Richard Juntunen, Chief
Abandoned Mine Reclamation Bureau
Montana Department of State Lands



THE SECRETARY OF THE INTERIOR
WASHINGTON

MESSAGE FROM SECRETARY OF THE INTERIOR DON HODEL
ON THE OCCASION OF THE 8TH ANNUAL
NATIONAL ABANDONED MINE LANDS CONFERENCE
Billings, Montana
August 10-15, 1986

Greetings to everyone participating in the 8th Annual National Abandoned Mine Lands Reclamation Conference. I am pleased to have the opportunity to participate in this conference, even if only by proxy.

I want to share a few thoughts with you on why surface mine reclamation is so important to America. Our industrial strength and economic security, both now and in the years ahead, necessitate the development of coal resources for energy without permanently scarring the land. President Reagan and I recognize coal's irreplaceable contribution to the energy mix. Likewise, we are cognizant of both the current environmental considerations and the consequences of past, unregulated coal mining. The national goal, therefore, is balance between energy development and environmental protection.

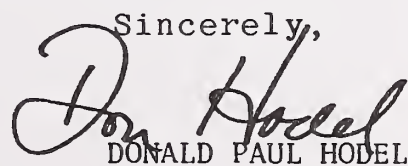
I firmly believe that it is not an "either-or" proposition. We can have both. We must continue to work toward the President's goal of enhancing America's ability to meet our energy and mineral needs with domestic resources, while benefiting the environment at the same time.

Your organization is crucial because there are still Americans who feel energy development and reclamation are contradictory goals. Based on your scientific knowledge and practical expertise, you are in a position to play a primary role not only in contributing to the balance between energy development and environmental protection, but also in helping the general public understand mining and reclamation.

The work you do is exemplary of the goals of the national public awareness campaign, "Take Pride in America; this land is your land," which was established to encourage all citizens to be responsible stewards for America's public lands and natural resources. We take pride in America's ability to produce the coal we need and to care for the land we so greatly treasure. You may justly take pride in your accomplishments.

I hope your meeting is productive in the exchange of ideas and in strengthening and broadening America's pride in the natural resources of our Nation.

With best wishes and warmest personal regards.

Sincerely,

DONALD PAUL HODEL

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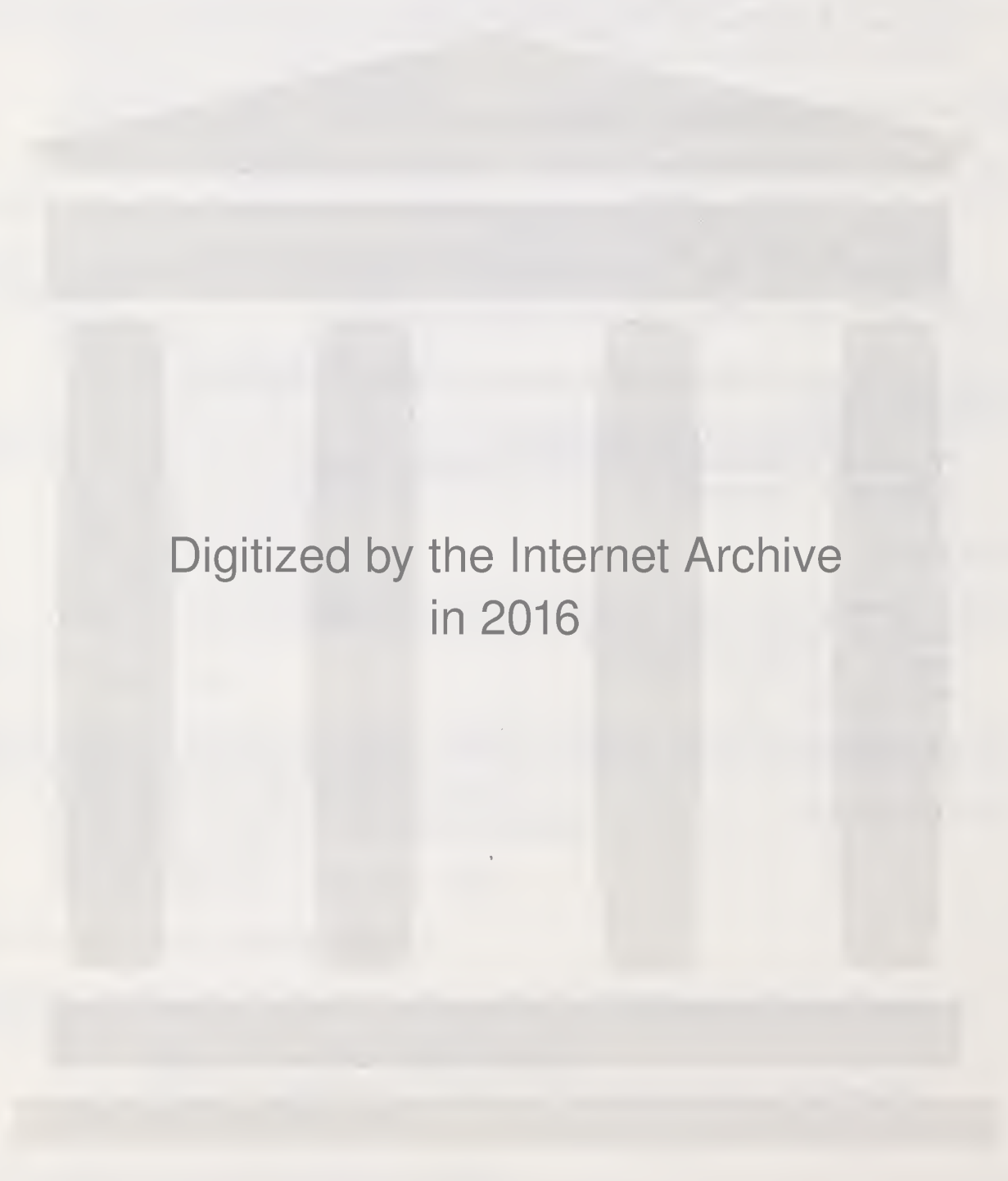
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ITINERARY

EIGHTH ANNUAL NATIONAL ABANDONED MINE LANDS CONFERENCE August 10-15, 1986 Billings, Montana

Sunday, August 10, 1986

2:00 pm - 7:00 pm

Registration

6:00 pm - 9:00 pm

Mixer for Attendees and Guests

Monday, August 11, 1986

8:00 am - 8:30 am

General Session

Conference Welcome

Conference Orientation

8:30 am - 10:00 am

1. RESEARCH AND DEVELOPMENT

Moderator:

Robert R. Tittle, Jr.
U.S. Office of Surface Mining
Washington, DC

Speakers:

Paul M. Marcus
U.S. Office of Surface Mining
Washington, DC
"Status of the AML Research
Program"

Ann Kim

U.S. Bureau of Mines
Pittsburgh, Pennsylvania
"Signature Criteria for
Monitoring Fires in
Abandoned Underground Coal
Mines"*

Speakers:

Rick Lucero
Colorado School of Mines
Research Institute
Golden, Colorado
"Use of Foaming Mud Cement
to Terminate Underground
Coal Fires and to Control
Subsidence of Burn Cavities"*

Dr. Marian Mazurkiewicz
University of Missouri
Rolla, Missouri

"The Location, Extinguishing
and Reignition Inhibition
of Refuse and Underground
Fires Through High Pressure
Waterjet Excavation, Mist
Cooling and Explosive
Injection of Inert Material"*

8:30 am - 10:00 am

2. HISTORICAL REQUIREMENTS

Moderator:

Dr. Eric Margolis
New Haven, Connecticut

Speakers:

Rex Wilson
U.S. Office of Surface Mining
Pittsburgh, Pennsylvania

Marcella Sherfy
Montana State Historic
Preservation Office
Helena, Montana

Lynn Fredlund
GCM Services Inc.
Butte, Montana

Bill Powell
U.S. Office of Surface Mining
Casper, Wyoming

* Underlined articles are re-printed in this document.

10:15 am - 12:00 pm

3. WETLANDS

Moderator:

Mike Hiel

Montana Dept. of State Lands
Helena, Montana

Speakers:

Dr. Robert Kleinmann
U.S. Bureau of Mines
Pittsburgh, Pennsylvania
"Constructed Wetlands for
Treatment of Mine Water--
Successes and Failures"*

Douglas A. Keplar

The EADS Group

Clarion, Pennsylvania
"Manganese Removal From Mine
Drainage by Artificial
Wetland Construction"*

J. David Holm

Colorado Department of
Natural Resources
Denver, Colorado

"Ecological, Design, and
Regulatory Considerations
for Wetlands Treatment
of Mine Discharge"*

Dr. Donald A. Hammer

Tennessee Valley Authority
Norris, Tennessee

"Man-Made Wetlands for
Acid Mine Drainage Control"*

1:30 pm - 3:00 pm

6. RESEARCH & DEVELOPMENT II

Moderator:

Paul M. Marcus

U.S. Office of Surface Mining
Washington, DC

10:15 am - 12:00 pm

4. PNEUMATIC STOWING AND
MINE SEALING TECHNIQUES

Moderator:

Garth Anderson

North Dakota Public
Service Commission
Bismarck, North Dakota

Speakers:

Cheri and Russell Eby
Eby Mine Services
Brighton, Colorado
"Adit Sealing and
Subsidence Control
Techniques"

Eric Powell

Pneumatic Techniques, Inc.
Sewickley, Pennsylvania
"Mine Sealing by Pneumatic
Stowing--Help for the
Smaller Contractor"*

James M. Roberts

SRW Associates Inc.
Pittsburgh, Pennsylvania
"Remote Pneumatic Stowing
in Abandoned Room and Pillar
Mines"*

1:30 pm - 3:00 pm

7. TITLE IV LEGISLATIVE UPDATE

Moderator:

Ellis Knows Gun

Crow Tribe Office of
Reclamation, Crow Agency,
Montana

10:15 am - 12:00 pm

5. FEDERAL OVERSIGHT

Moderator:

Raymond L. Lowrie

U.S. Office of Surface Mining
Denver, Colorado

Speakers:

Dr. Allen O. Perry
U.S. Office of Surface Mining
Washington, DC

Robert Baker

Ohio Department of
Natural Resources
Columbus, Ohio

Patrick C. Park

West Virginia Department of
Energy
Charleston, West Virginia

Richard L. Juntunen

Montana Department of
State Lands
Helena, Montana

1:30 pm - 3:00 pm

8. NATIONAL INVENTORY--
DISCRETIONARY SHARE ALLOCATION

Moderator:

Dr. Allen O. Perry

U.S. Office of Surface Mining
Washington, DC

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1:30 pm - 3:00 pm

6. RESEARCH & DEVELOPMENT II

Speakers:

Robert A. Bauer
Illinois State Geological
Survey, Champaign, Illinois
"Application of Time Domain
Reflectometry to Subsidence
Monitoring"*

Dr. Don Steeples
Kansas Geological Survey
Lawrence, Kansas
"Cavity Detection by High
Resolution Reflection
Seismology"*

Dr. S. S. Peng
West Virginia University
Morgantown, West Virginia
"Guidelines for Subsidence
Abatement Over Abandoned Mine
Lands"

1:30 pm - 3:00 pm

7. TITLE IV LEGISLATIVE UPDATE

Speakers:

A. David Lester
Council of Energy Resource
Denver, Colorado

Phil Zahne
Navajo Tribe, Reclamation
Section
Window, Rock, Arizona

Don Ami
Hopi Tribe, Mining and
Reclamation Enforcement
Kykotsmovi, Arizona

Michael L. Kastl
Oklahoma Conservation
Commission
Oklahoma City, Oklahoma

3:15 pm - 4:30 pm

General Session II

State Programs Slide Presentation

"Unusual or Unique Reclamation Techniques"

1:30 pm - 3:00 pm

8. NATIONAL INVENTORY--
DISCRETIONARY SHARE ALLOCATIONS

Speakers:

Theodore H. Ifft
U.S. Office of Surface Mining
Washington, DC

James Evans
U.S. Office of Surface Mining
Washington DC

Daniel P. Chargo
Kansas Corporation Commission
Pittsburg, Kansas

Roger L. Williams
Virginia Department of Mines,
Minerals, and Energy
Big Stone Gap, Virginia

Sue Massie
Illinois Abandoned Mine Lands
Reclamation Council
Springfield, Illinois

Tuesday, August 12, 1986

8:30 am - 10:00 am

9. ACID MINE DRAINAGE

Moderator:

Mohammad Baloch
U.S. Office of Surface Mining
Washington, DC

Speakers:

Vijay Rastogi
B.F. Goodrich Company
Akron, Ohio
"Reclaiming Abandoned Mine
Lands Using Controlled
Release Bactericides--
A Case Study"*

8:30 am - 10:00 am

10. CONTRACT MANAGEMENT

Speakers:

Robert J. Smith
Wickwire, Gavin and Gibbs
Madison, Wisconsin
"Avoiding Risks, Claims and
Liability in Construction
Projects and Reviewing
Construction Contract
Documents and Procedures"

8:30 am - 10:00 am

11. STATE-OF-THE-ART
RECLAMATION

Moderator:

Dr. Bernard Maynard
U.S. Office of Surface Mining
Pittsburgh, Pennsylvania

Speakers:

Ginger Kaldenbach
U.S. Office of Surface Mining
Denver, Colorado
"Comparison of Techniques
Used for Sealing Steeply-
Inclined Slope Entries"

* Underlined articles are re-printed in this document.

8:30 am - 10:00 am	8:30 am - 10:00 am	8:30 am - 10:00 am
9. ACID MINE DRAINAGE	10. CONTRACT MANAGEMENT	11. STATE-OF-THE-ART RECLAMATION
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Speakers: Patricia M. Erickson U.S. Bureau of Mines Pittsburgh, Pennsylvania "Control of Acid Mine Drainage: An Overview of Recent Developments"		Speakers: Len F. Marrs Chen and Associates, Inc. Casper, Wyoming <u>"Hazard Reduction Techniques Used for Pit Subsidence Near Hanna, Wyoming"</u> *
Dr. John Holbrook U.S. Office of Surface Mining Pittsburgh, Pennsylvania "OSMRE Research in Acid Mine Drainage Abatement"		Dr. Bernard Maynard U.S. Office of Surface Mining Pittsburgh, Pennsylvania "Recent Developments in Mine Shaft Reclamation"
10:15 am - 12:00 pm	10:15 am - 12:00 pm	
12. LAND RECLAMATION STRATEGIES IN EUROPE, AFRICA, AUSTRALIA AND SOUTH AMERICA	13. APPROPRIATIONS AND ALLOCATIONS	
-----	-----	-----
Moderator: Scott D. Spano Montana Department of State Lands Helena, Montana	Moderator: Theodore H. Ifft U.S. Office of Surface Mining Washington, DC	Speakers: Michael L. Kastl Oklahoma Conservation Commission Oklahoma City, Oklahoma
Speaker: Dr. Michael J. Chadwick Director Beijer Institute Centre for Resource Assessment and Management University of York Heslington, York, England	Speakers: Theodore H. Ifft U.S. Office of Surface Mining Washington, DC <u>John P. Crumrine</u> <u>U.S. Office Of Surface Mining</u> <u>Washington, DC</u>	
1:30 pm - 3:00 pm	1:30 pm - 3:00 pm	1:30 pm - 3:00 pm
14. SPOIL TOXICITY AND ACID PRODUCTION POTENTIAL	15. SUPERFUND AND ABANDONED MINE RECLAMATION	16. STATE-OF-THE-ART RECLAMATION II
-----	-----	-----
Moderator: Dr. John Holbrook U.S. Office of Surface Mining Pittsburgh, Pennsylvania	Moderator: Ben Mundie Montana Department of State Lands Helena, Montana	Moderator: Tim Hickmann Illinois Abandoned Mine Land Reclamation Council Springfield, Illinois

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1:30 pm - 3:00 pm

14. SPOIL TOXICITY AND ACID
PRODUCTION POTENTIAL

Speakers:

Dr. Douglas J. Dollhopf
Montana State University
Bozeman, Montana
"Rapid Weathering Technique
for Determining Total Lime
Requirement for Acid
Minesoils"

Kurt Anselmi
Wyoming Department of
Environmental Quality
Cheyenne, Wyoming
"Ameliorating the Adverse
Chemical and Physical
Properties of Bentonitic Clay"

Patricia M. Erickson
U.S. Bureau of Mines
Pittsburgh, Pennsylvania
"Acid Source Identification:
The Postmining Perspective"

1:30 pm - 3:00 pm

15. SUPERFUND AND
ABANDONED MINE RECLAMATION

Speakers:

Robert Walline
U.S. Environmental Protection
Agency, Denver, Colorado

Mary Ann Wright
Utah Department of Natural
Resources, Salt Lake City,
Utah

Michael Rubich
Montana Department of Health
and Environmental Sciences
Helena, Montana

David Stiller
Stiller and Associates
Helena, Montana

3:15 pm - 4:30 pm
General Session III
AML Program Overview

State Perspective
Michael L. Kastl
Oklahoma Conservation Commission
Oklahoma City, Oklahoma

OSM Perspective
Dr. Brent Wahlquist
U.S. Office of Surface Mining
Washington, DC

6:30 pm - 8:30 pm
Banquet Dinner

Keynote Speaker:
Jed D. Christensen, Director
U.S. Office of Surface Mining
Washington, DC

1:30 pm - 3:00 pm

16. STATE-OF-THE-ART
RECLAMATION II

Speakers:

Sue Massie
Illinois Abandoned Mine Land
Reclamation Council
Springfield, Illinois
"Buffalo Rock Earth Sculpture
Land Reclamation"*

Jack A. Muncie
and
Roger W. Bollinger
Tennessee Valley Authority
Norris, Tennessee
"Aerial Treatment Activities
for Revegetating Disturbed
Lands"*

Jon Ventura
U.S. Office of Surface Mining
Pittsburgh, Pennsylvania
"Non-Explosive Demolition of
Highwalls"*

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Wednesday, August 12, 1986

Thursday, August 13, 1986

Friday, August 15, 1986

8:30 am - 12:00 pm

Concurrent Meetings:
Association of Abandoned Mine
Land Programs

U.S. Office of Surface Mining

1:00 pm - 5:00 pm

Post-Conference Tour Begins
Travel from Billings to
Mammoth Hot Springs
(Figure 1)

8:00 am - 9:30 am

Travel from Mammoth Hot
Springs to Cooke City

9:30 am - 11:00 am

McLaren Mine Tailings Site:
Unreclaimed tailings site from
gold mining operations;
reclamation scheduled to begin
in 1987. Highlights include
problems with acid production
and elevated trace elements.

11:00 am - 2:00 pm

Travel from Cooke City to
Red Lodge

2:00 pm - 4:30 pm

Red Lodge Airport Site:
Reclaimed coal waste dump.

South Dump Site:
Reclaimed coal waste dump;
highlights include subsidence
reclamation, portal closures,
and acid mine drainage
problems.

North Dump Site:
Reclaimed coal waste dump next
to Rock Creek; visit includes
site dedication as "Coal
Miner's Park"

4:30 pm - 6:00 pm

Return to Billings

8:00 am - 9:15 am

Tour of Active Surface Coal
Mine:

Travel from Billings to
Absaloka Mine

9:15 am - 12:00 pm

Absaloka Mine Tour

1:00 pm - 2:15 pm

Return to Billings



FIGURE 1 -- POST-CONFERENCE TOUR ROUTE

SIGNATURE CRITERIA FOR MONITORING ABANDONED MINE FIRES

A. G. Kim
Chemist, Pittsburgh Research Center
Bureau of Mines
Pittsburgh, Pennsylvania

Abstract

Fires in abandoned coal mines and waste banks are relatively common, occurring in every coal producing state. Locating a fire in an abandoned underground coal mine has placed a serious constraint on the ability to extinguish such fires. Because combustion fumes travel the path of least resistance, surface evidence of the fire may not be directly above combustion zones. Likewise, aerial infrared surveys locate heated surface areas, but cannot discriminate subsurface temperature differences. The Bureau of Mines is developing a method of locating and monitoring underground fires in abandoned coal mines which combines borehole temperature and pressure measurements with the analysis of gas samples for standard combustion gases and hydrocarbon gases desorbed from heated coal.

In this laboratory study, gases from mildly heated samples of coal and coal refuse are studied to develop a "signature" for indicating coal sample temperature. Controlled temperature environments are between 100° and 250°C and the airflow rates over the sample are between 1 and 2 scf/hour. A mixture of air and nitrogen is used at temperatures above 200°C to control self-heating of the coal and keep it at the desired temperature. Gas samples are taken periodically and analyzed by gas chromatography.

A hydrocarbon ratio, R_1 is defined as:

$$R_1 = (1.01[\text{THC}] - [\text{CH}_4]) / ([\text{THC}] - .01) * 1000$$

where [THC] is the concentration of total hydrocarbons. When [THC] = 0, the ratio is defined as zero; when methane is the only hydrocarbon, the value of R_1 is 10. At temperatures above 100°C, this ratio increases with temperature, with most values above 100. Changes in the ratio (R_1) are related to changes in the temperature of the sample and can provide an effective signature criteria for monitoring abandoned coal mine fires.

INTRODUCTION

Fires in abandoned mines and waste banks are a relatively common occurrence in coal mining areas. A survey in the 1970's by the Bureau of Mines identified 292 waste bank fires and 261 fires in abandoned mines (Johnson and Miller 1978; McNay 1971). Fires have been located in every coal producing state (Table 1).

Table 1. Abandoned mined land fires.

State	WASTE BANK FIRES*		MINE FIRES**	
	Number	Estimated Reclamation Cost (in \$million)	Number	Estimated Reclamation Cost (in \$million)
Alabama	6	25.3	-	-
Alaska	-	-	3	.04
Arizona	-	-	10	.3
Colorado	15	25.7	47	1.6
Illinois	4	12.5	-	-
Kentucky	27	37.0	5	.5
Maryland	2	0.1	2	.3
Montana	3	0.5	65	0.9
New Mexico	-	-	9	0.2
North Dakota	-	-	15	0.2
Ohio	6	3.2	7	.9
Oklahoma	1	.1	-	-
Pennsylvania	74	192.2	42	66.8
South Dakota	-	-	2	.02
Texas	-	-	1	.01
Utah	4	4.9	17	.6
Virginia	17	6.3	-	-
Washington	1	5.3	2	.06
West Virginia	132	153.1	8	1.0
Wyoming	-	-	26	2.1
Total	292	466.2	261	75.6

* Mc Nay, L. M. 1971. Coal refuse fires, an environmental hazard. BuMines IC 8515:29-47.

** Johnson, W. and G. C. Miller. 1978. Abandoned coal-mined lands, nature, extent and cost of reclamation. BuMines 1978:28.

Abandoned mine fires can present a serious health, safety and environmental hazard from the emission of toxic fumes, and from subsidence, and the deterioration in air quality. Fires usually depress property values for affected land and adjacent areas. Although there are several fire extinguishment methods, the cost of controlling an abandoned coal fire is usually high (\$1 million), and the success rate is often low (Chaiken et al. 1980; Griffith, Magnuson, and Toothman 1960; Magnuson 1974).

In almost all cases, the application of a control method is made more difficult by the inability to accurately locate the fire. Usually a fire in an abandoned underground mine or in a waste bank is detected because smoke is emitted along an outcrop or through natural vents and fractures. Because hot gases follow the path of least resistance, surface evidence of venting gases may not be directly above the subsurface fire zones. Likewise, aerial infrared

photography detects surface areas heated by gases exhausted from the fire zone. Although the infrared technique can detect very small differences in temperatures, it detects only heated areas which are essentially at the surface. Attempts to extrapolate surface data to underground locations require that gases migrate upward by straight line paths, a condition which is not usually met. Also, the interpretation of aerial infrared photos can be complicated by the presence of heat absorbing surface features.

Determining subsurface temperatures through boreholes can provide more information, however the results are highly variable. Generally thermocouples measure the highest temperature within a volume of 1-2 cubic feet immediately surrounding the thermocouple tip. Due to the fact that: 1) abandoned coal fires are usually smoldering combustion; 2) such fires tend to be discontinuous, and 3) coal and the surrounding rock can serve as an insulating medium, it is possible to measure almost normal underground temperatures within 10 feet of an active combustion zone. Experience with methods such as simple borehole temperatures, which are based on physical properties, has generally shown them to lack accuracy and sensitivity.

Several other indicators, based on the evolution of products of combustion, have been used to locate underground heated areas with mixed results. Two commonly used indicators based on the evolution of CO_2 and CO are the Jones Trickett ratio and the airfree ratio of CO_2 to CO (Chaiken, Singer and Lee 1979; Jones and Trickett 1955). The Jones Trickett ratio (JTR) related the production of CO_2 , CO and H_2 to oxygen depletion:

$$\text{JTR} = (\text{CO}_2 + .75 \text{ CO} - .25 \text{ H}_2) / (\text{N}_2 / 3.76 - \text{O}_2)$$

During the Bureau's test of the Burnout Control system at Calamity Hollow (Chaiken et al. 1984; Chaiken et al. 1979; Kim et al. 1984; Soroka et al. 1985) where gases were withdrawn from an underground mine fire, the Jones Trickett ratio, on the average, seemed to be a good indicator of combustion efficiency, independent of short-term changes in exhaust temperature, exhaust flow rate and heat production. However, the JTR did not correspond directly with measured temperatures.

The airfree ratio of CO_2 to CO, as determined in the laboratory, is three for burning coal. In Bureau fire control studies at Calamity Hollow and at Renton, Pennsylvania, the airfree ratio of CO_2 to CO varied between 10 and infinity, and showed little correlation to temperature.

In controlled laboratory tests, the production of submicron particulates was related to combustion temperatures (Kim et al. 1984; Litton 1981). Combined with a sensitive detection system, the Bureau's SMPD fire detector uses the appearance of submicron particles as an early warning device for fires in active mines. Unfortunately the use of the SMPD at abandoned underground mine fires has produced ambiguous results, probably due to the high moisture content of the gases.

The use of these indicators depends on measurable changes related to combustion. In abandoned mines, as little as 1% of the coal and carbonaceous material may be involved in smoldering combustion. Also, CO_2 may be produced and oxygen consumed by processes other than combustion, such as bacterial metabolism or ambient temperature oxidation. If the concentration of

oxygen is greater than 19%, errors in calculated ratios tend to become very large even when measurement error is relatively small. The dilution factor, the length of the ventilation pathway and the relative sampling volume may also be factors in the generally low accuracy of these combustion indicators when used at abandoned mines.

In conjunction with its work on innovative methods of controlling abandoned underground and waste bank fires (Chaiken 1980; Chaiken et al. 1981), the Bureau is developing a borehole diagnostic system to accurately determine the location and extent of underground abandoned mine fires and to establish measurable criteria for determining when such fires are extinguished. The Bureau's diagnostic system is based on temperature and the analysis of the underground atmosphere for low molecular weight hydrocarbon gases. At ambient temperature and above, hydrocarbon gases are desorbed from coal (Kim 1973, 1977). At ambient temperature, over 95% of the emitted gas is methane (Figure 1). As the temperature of the coal increases, the concentration of C_2 to C_5 hydrocarbons increases. Because relatively low temperatures are involved, the hydrocarbon ratio is sensitive and applies to larger masses of coal. Since a ratio is used, if the concentration is above the detection limits, dilution is not a factor. The hydrocarbon ratio is independent of the concentration of other components such as oxygen, and temperature dependent desorption is the only mechanism by which the hydrocarbons are produced. Therefore, the hydrocarbon ratio is considered the most sensitive and positive indicator for locating heated zones in abandoned underground mines. The method has been applied to field situations, and the purpose of this study is to develop a data base relating hydrocarbon ratio to temperature under controlled conditions, and to correlate this with data from extinguishment projects.

EXPERIMENTAL METHOD

In the laboratory portion of the study, an eight-inch tubular combustion furnace is used to heat the samples. Parameters in the system include temperature, air flow rate, concentration of oxygen, and heating rate. A one-kilogram sample is placed in a stainless steel sample boat. Thermocouples and gas sampling tubes are placed at the air inlet, in the sample boat and downstream of the furnace (Figure 2). There is provision for adding a sample of rock or other material downstream of the furnace, to determine if the concentration of combustion products is affected by adsorption. A personal size sampling pump is used to withdraw gas samples which are collected in vacutainers. There is provision for connecting the sampling system to a Hewlett-Packard GC5880A gas chromatograph, but at present, samples are taken to the Bureau's analytical laboratory and analyzed by GC for O_2 , N_2 , CO_2 , CO, H_2 , Ar, methane and C_2 to C_5 hydrocarbons, including unsaturates. The hydrocarbons are determined by flame ionization detector with a sensitivity of 1 ppm. Other gases are detected by thermal conductivity detector with a sensitivity of .01%. With both detectors, the accuracy is considered $\pm 2\%$ of the amount present.

In the laboratory tests, compressed air at the rate of 1 to 2 cf/hour is used. At temperatures above $200^\circ C$, nitrogen is added to the airstream to reduce the concentration of O_2 , in order to control the tendency of the coal to self-heat. A mixing tank is used to insure constant composition of the airstream and to have air enter the furnace at atmospheric pressures. For each coal sample, at

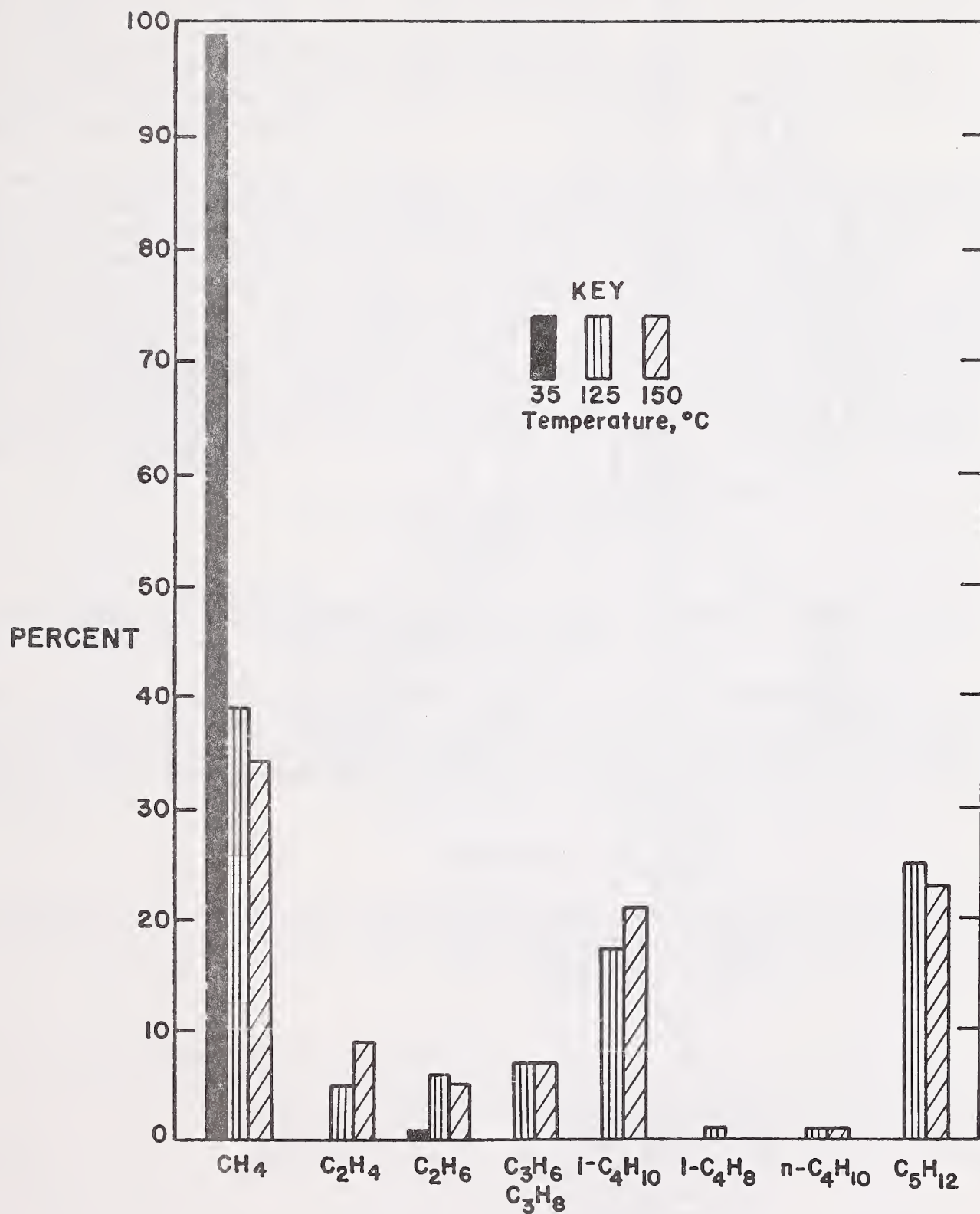


Figure 1. Relative composition of hydrocarbon gas.

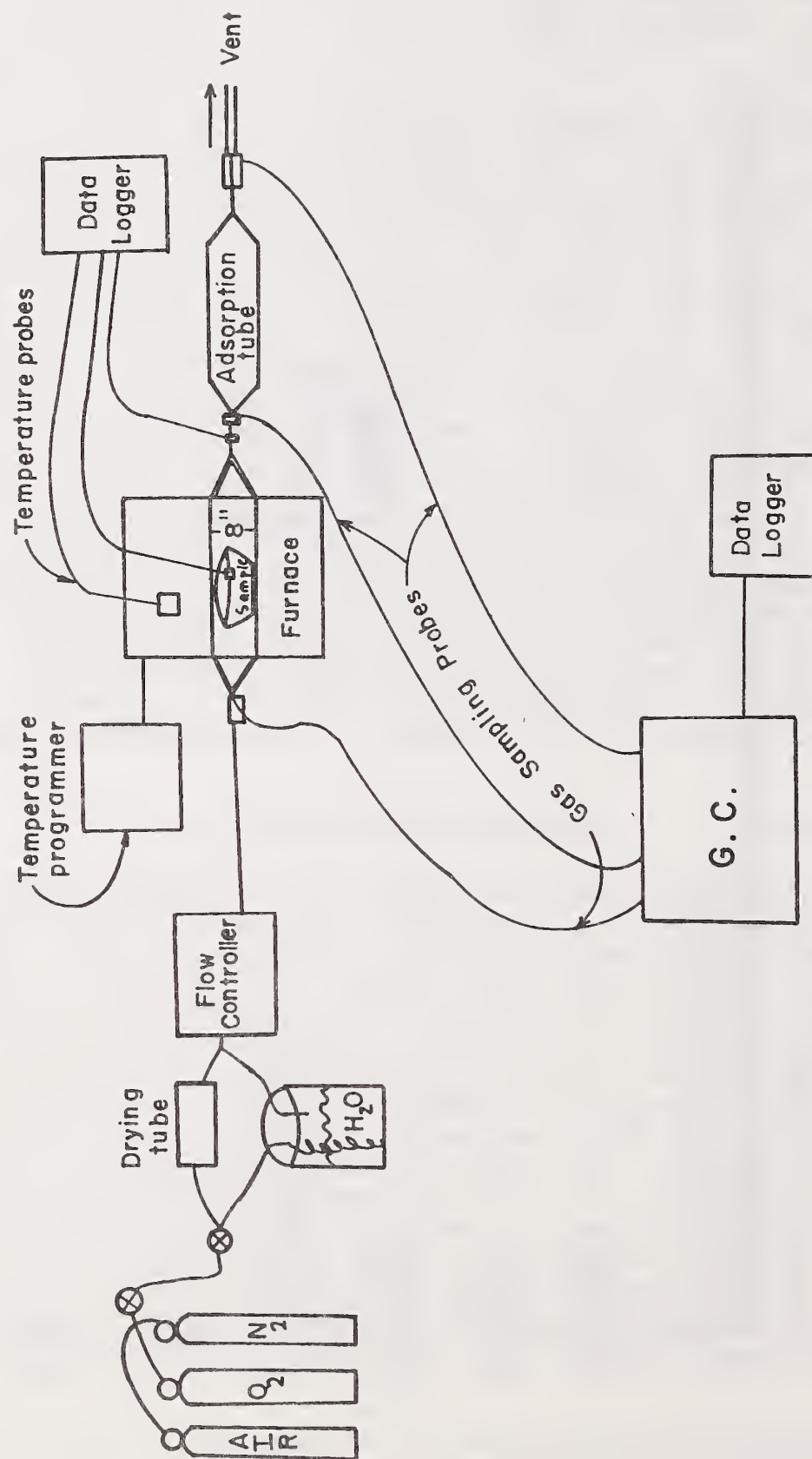


Figure 2. Block diagram of laboratory equipment for gas diagnostic study.

least two tests are conducted (Figure 3). The first is an extended test in which the furnace temperature is raised from ambient to 250°C in 50°C increments. For each increment, the temperature is maintained at that level for approximately three days. Each intermittent test requires approximately two weeks. In a second test, the temperature controller is set at 250°C, and the temperature is allowed to rise continuously. The furnace temperature is held at 250°C for several hours and then the furnace is allowed to cool. The continuous test takes approximately five days, and samples are taken during heating and cooling phases.

In early tests, a simple ratio of the concentration of higher hydrocarbons (C_2 to C_5) to the concentration of methane was used. However, the value of this ratio was zero when no higher hydrocarbons were detected independent of the concentration of methane. Also, the data were evaluated by computer. If the methane concentration was zero, the computer would terminate the program since division by zero is an illegal operation. Therefore, it was necessary to define a hydrocarbon ratio which would: 1) equal zero when the concentration of total hydrocarbons was zero; 2) have a unique value when methane was the only hydrocarbon; 3) eliminate the possibility of division by zero, and 4) increase as the temperature of the sample increased. The ratio defined to meet these criteria is:

$$R_1 = \frac{1.01[THC] - [CH_4] \times 1000}{[THC] + C}$$

where [THC] = total hydrocarbons, ppm; $[CH_4]$ = methane, ppm; and C = .01 ppm, a constant small concentration greater than zero.

When no hydrocarbons are detected, the ratio is zero. When methane is the only hydrocarbon, R_1 equals 10. A value of 1000 or more indicates that the higher hydrocarbons are present but no methane. The ratio, as defined, is an increasing function of the percentage of higher hydrocarbons in the gas mixture.

RESULTS

Intermittent and continuous heating tests have been completed for samples of the Pittsburgh and Freeport coals and of the Albright Waste Bank (Table 2).

Table 2. As received coal analysis.

Sample Source	Allegheny County, Pennsylvania Pittsburg Seam	Allegheny County, Pennsylvania Freeport Seam	Preston County, West Virginia Albright Coal Waste
Moisture	1.4	1.6	9.06
Ash	4.76	6.1	42.28
Volatile Matter	37.36	37.8	17.52
Fixed Carbon	56.48	54.5	31.2
Moist BTU	14205.0	14196.0	6719.0

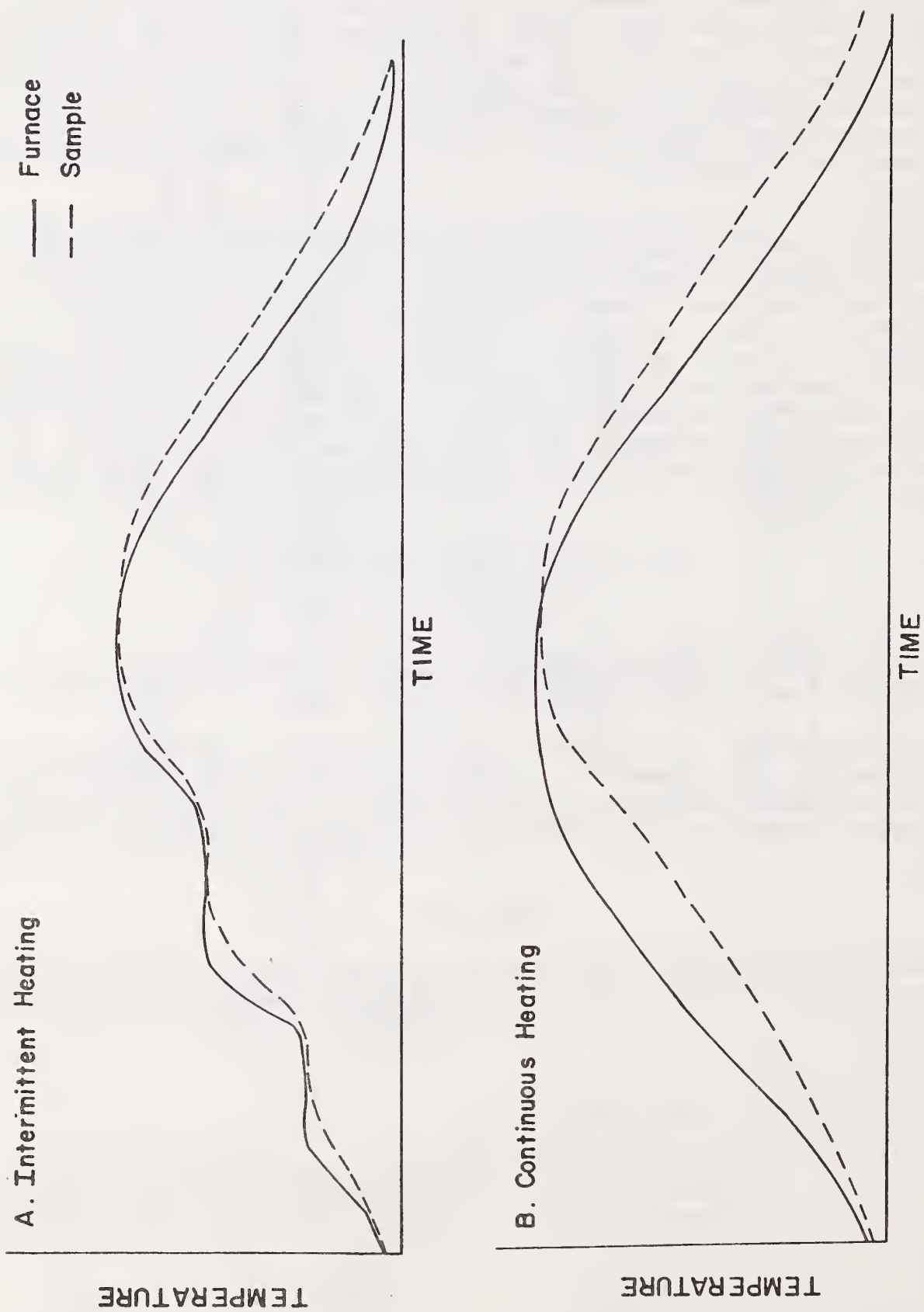


Figure 3. Intermittent and continuous heating regimes for gas diagnostic study.

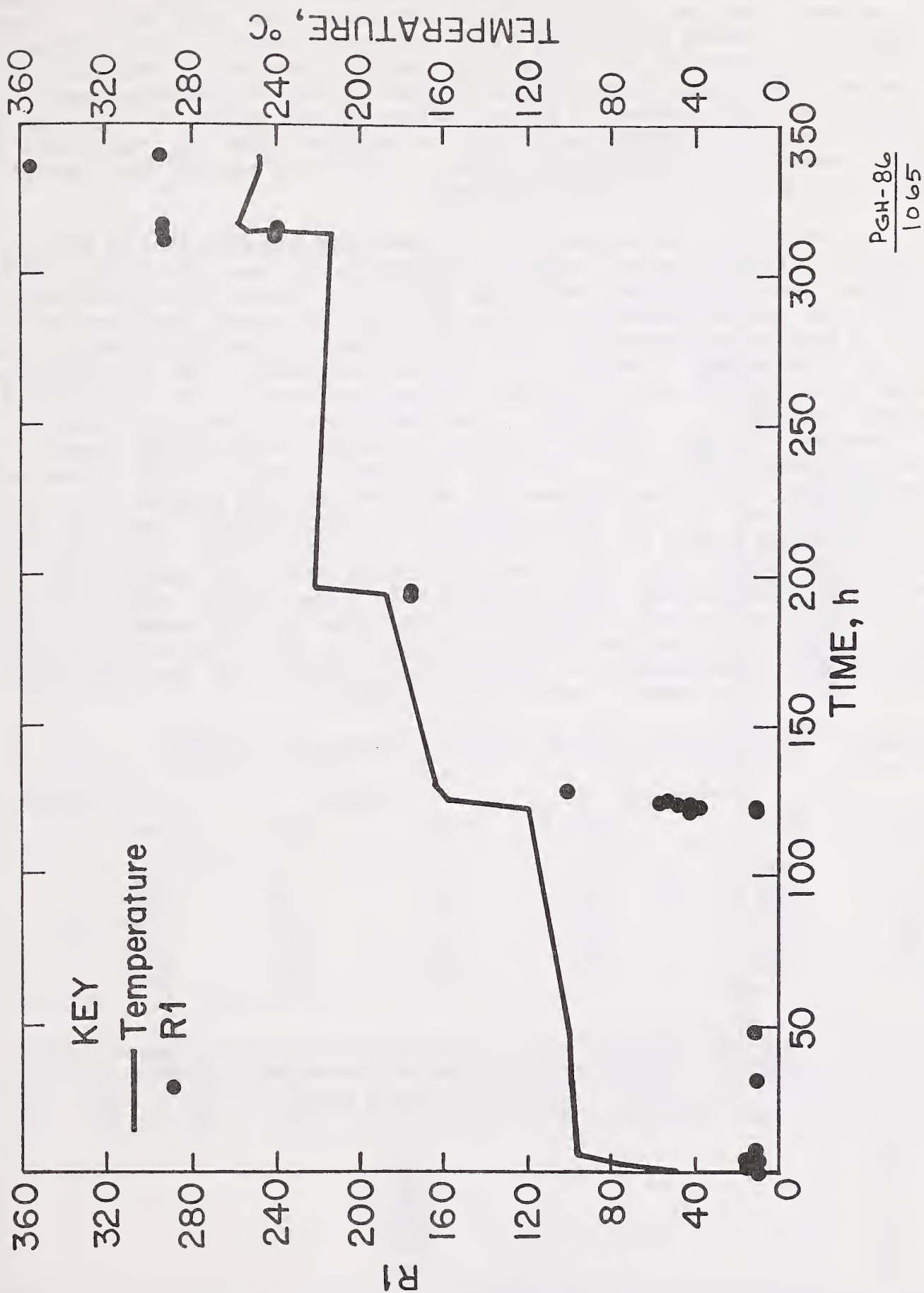


Figure 4. Variation of hydrocarbon ratio and temperature with time, Freeport coal.

An incremental test took approximately three weeks to complete, and in general, showed that as the temperature increased, the value of R_1 increased (Figure 4). During the extended test, the concentration of total hydrocarbons [THC] decreased with time (Figure 5), probably because the emission rate is a function of the concentration within the coal as well as the temperature. The incremental tests produced a larger number of data points, but gave no more reliable or accurate data than could be obtained from the continuous tests which could be completed in one week. Therefore, most of the present data analysis is based on the continuous tests.

For all samples, as the temperature increased the concentration of total hydrocarbons [THC] increased with the difference between the [THC] and the methane concentration also increasing (Figure 6). After the coal was heated to 250°C, the heating element was turned off, and the sample was allowed to cool. As the temperature decreased, the concentrations of total hydrocarbons and of methane decreased. However, at a given temperature, the concentration of total hydrocarbons and of methane were not the same as the coal heated and cooled (Figure 7). Therefore, the calculated value, R_1 , varied with temperature and was different during the heating and cooling phases of the tests (Figures 8, 9, 10). The way in which the value of R_1 varied during heating and cooling was different for all three samples (Figure 11). For the Pittsburgh coal, R_1 was greater than 500 during heating and 200 or less during cooling (Table 3) with a maximum R_1 value of 550. With the Albright Waste Bank sample, R_1 values were generally below 200 during heating and over 200 during cooling, with a maximum R_1 value of 325. With the Freeport coal, the R_1 values were generally low and similar during heating and cooling. The maximum R_1 value for the Freeport coal was 400. The samples varied in the maximum concentration of hydrocarbons emitted and the temperature at which an R_1 value above 50 was detected (Table 4).

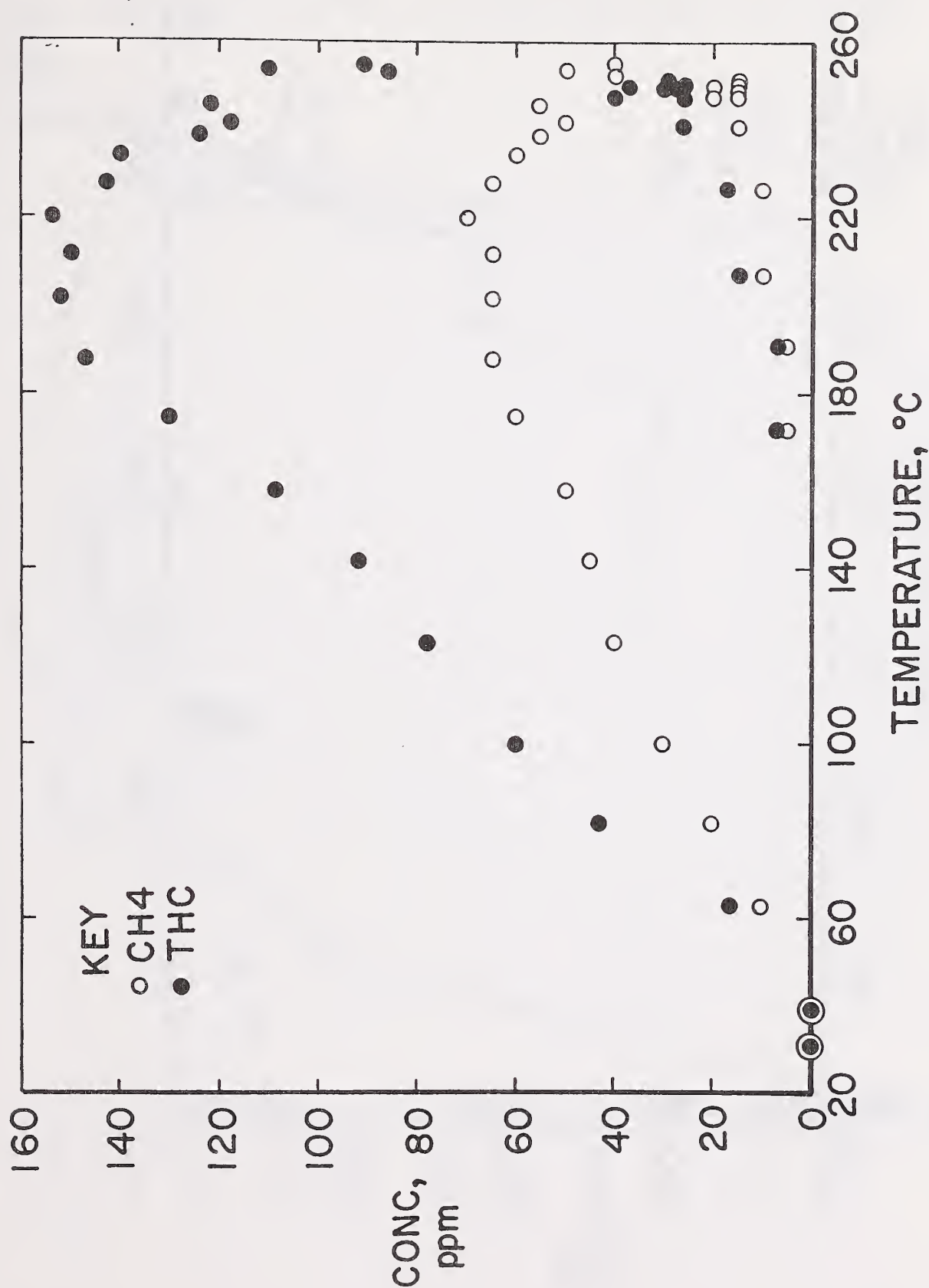
Table 3. Hydrocarbon ratios (R_1) during heating and cooling.

T, °C	Pittsburgh		Albright		Freeport	
	Heat	Cool	Heat	Cool	Heat	Cool
100	520	N/A	50	10	30	10
150	540	150	70	10	40	30
200	590	180	80	225	50	60
225	550	200	150	275	75	125
250	550	550	325	325	400	400

Table 4. Maximum concentration of hydrocarbons during continuous heating.

Sample ID	[THC] maximum ppm	T1*
P1	150	60
P2	500	60
F1	8200	240
F2	8900	230
A1	600	200
A2	165	100

* T1 is temperature (°C) at which R_1 is greater than 50.



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Figure 6. Variation in hydrocarbon concentrations with temperature during continuous heating, Pittsburgh coal.

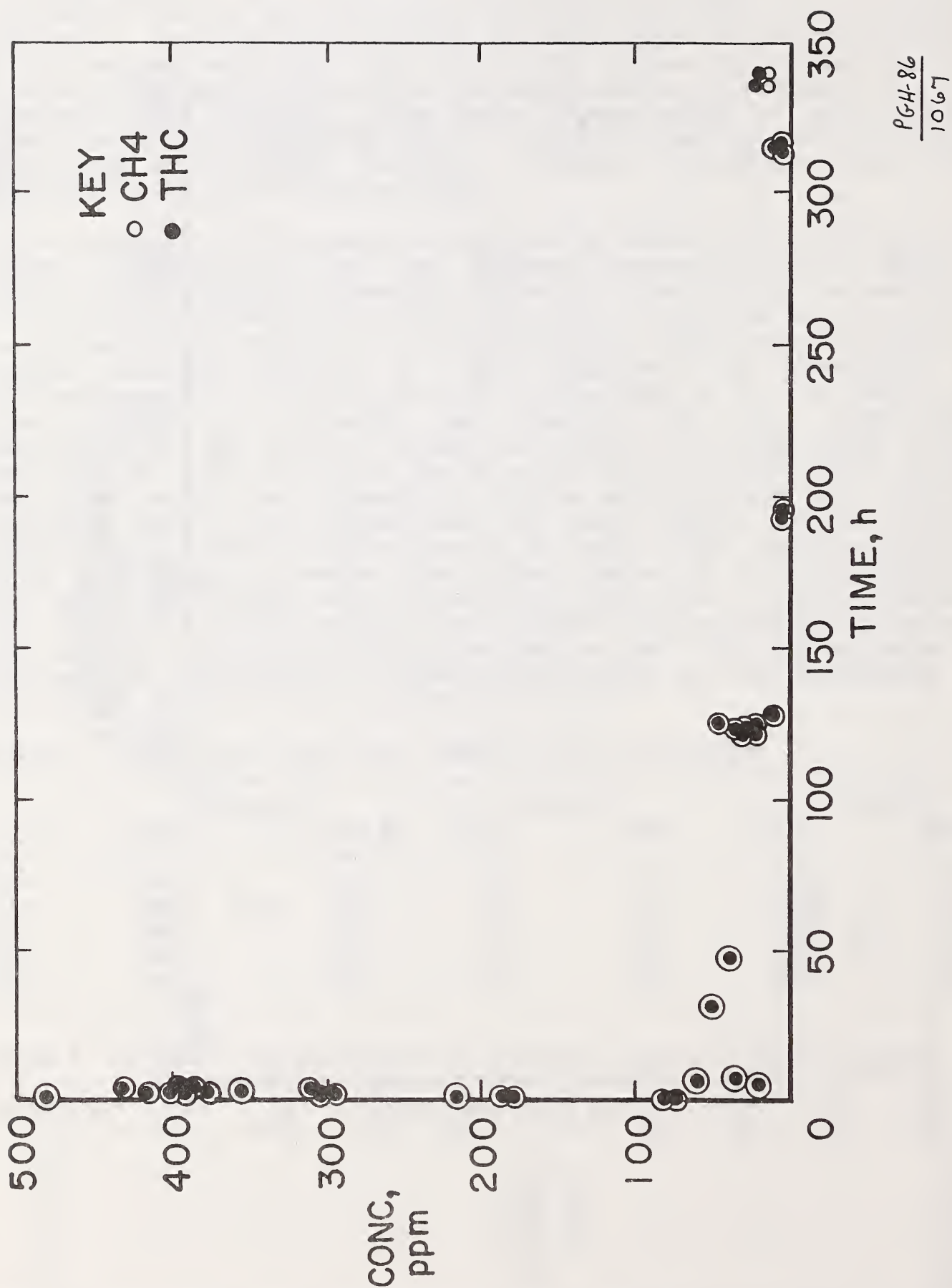


Figure 5. Variation in hydrocarbon concentration with temperature during intermittent heating, Freeport coal.

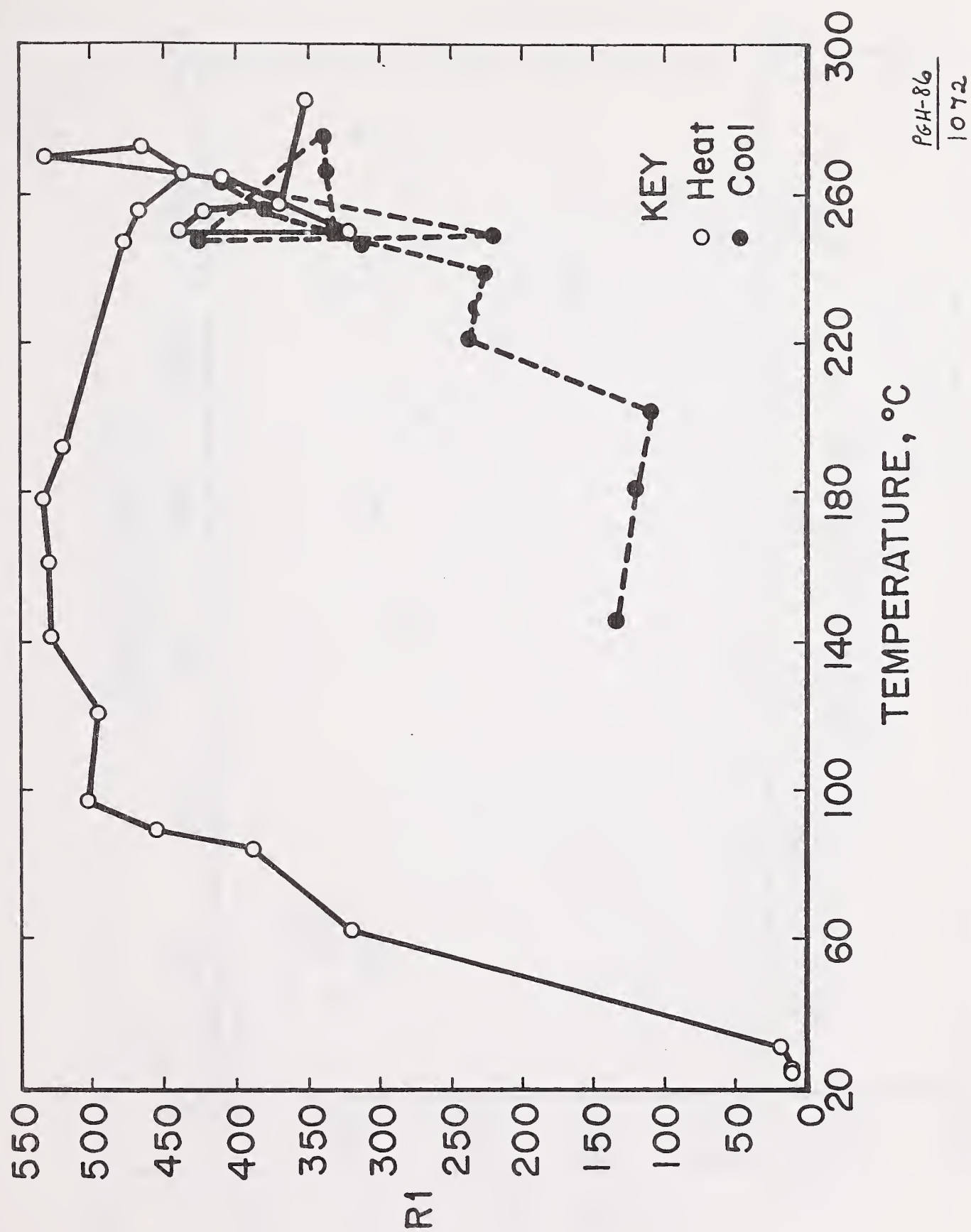
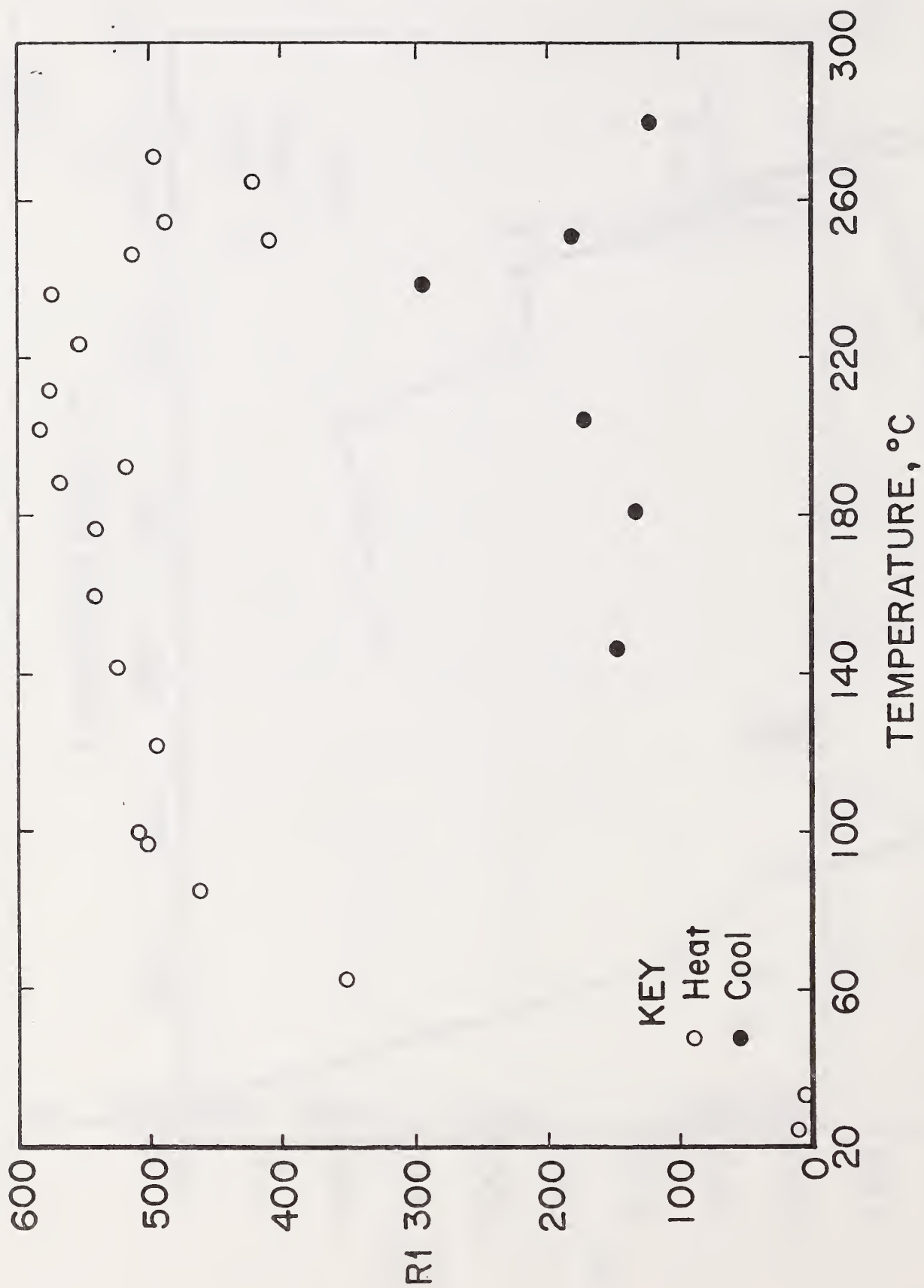


Figure 7. Variation of hydrocarbon ratio with temperature, Pittsburgh coal.



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Figure 8. Mean hydrocarbon ratios, Pittsburgh coal.

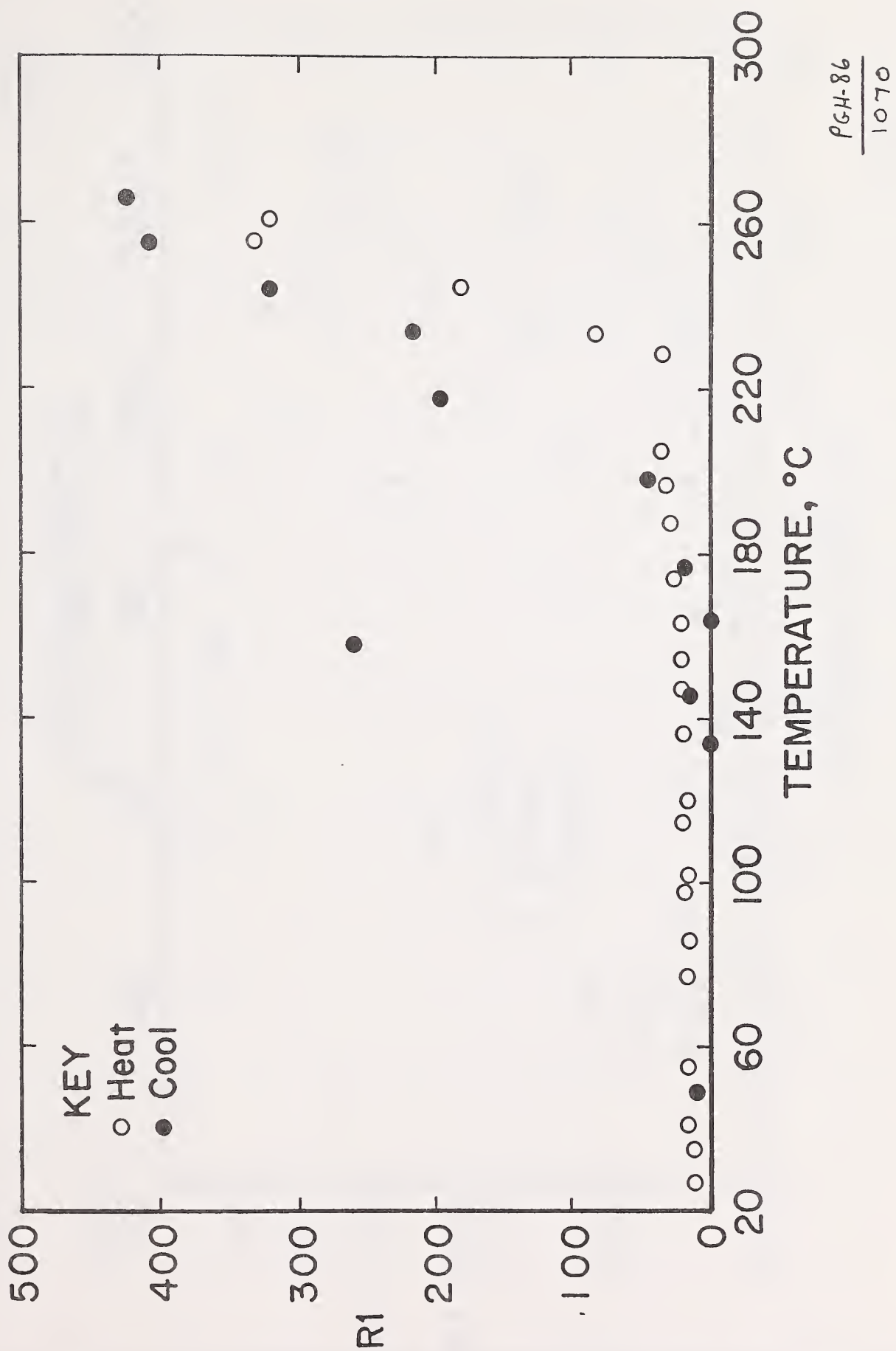


Figure 9. Mean hydrocarbon ratios, Freeport coal.

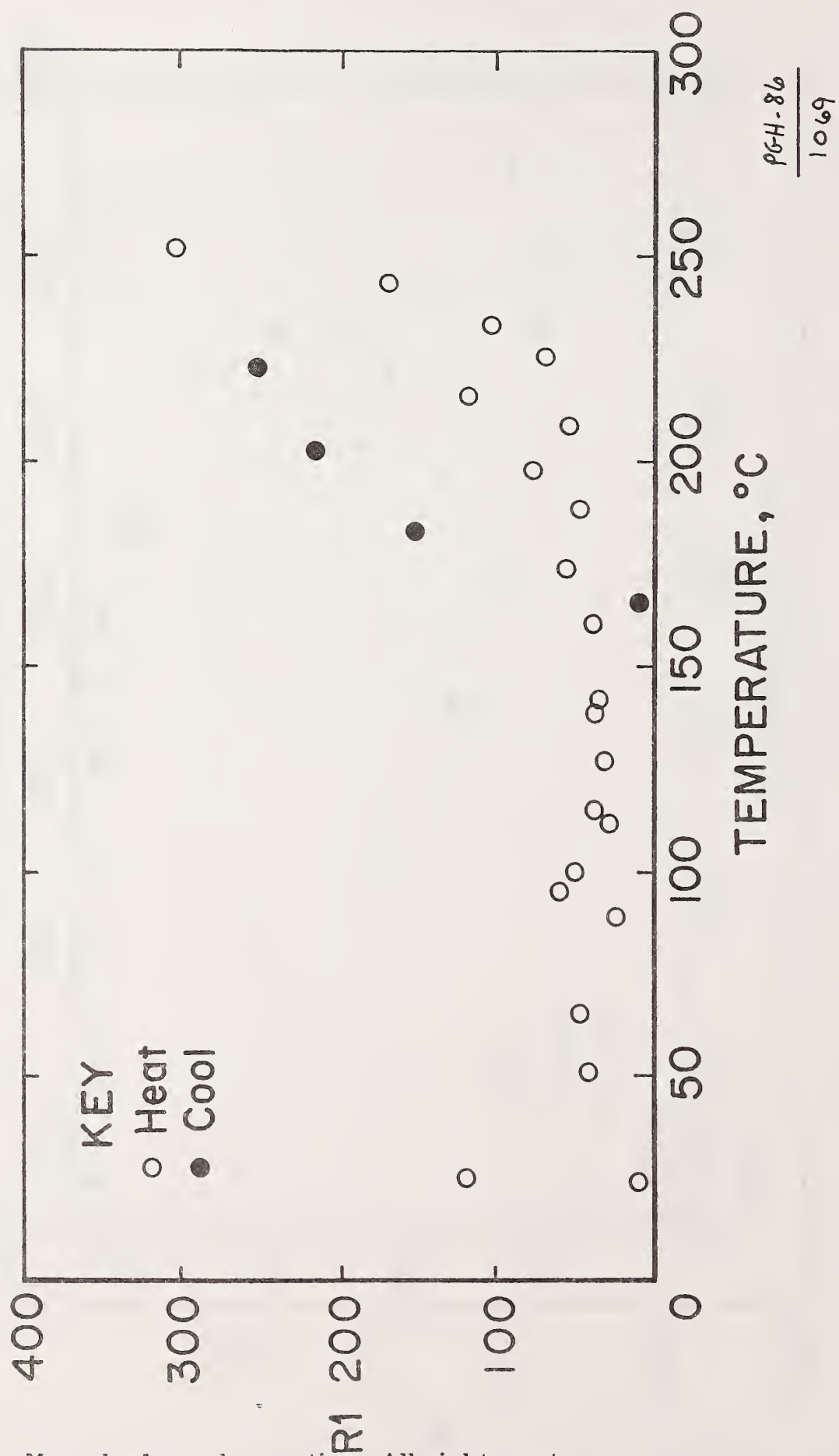


Figure 10. Mean hydrocarbon ratios, Albright waste.

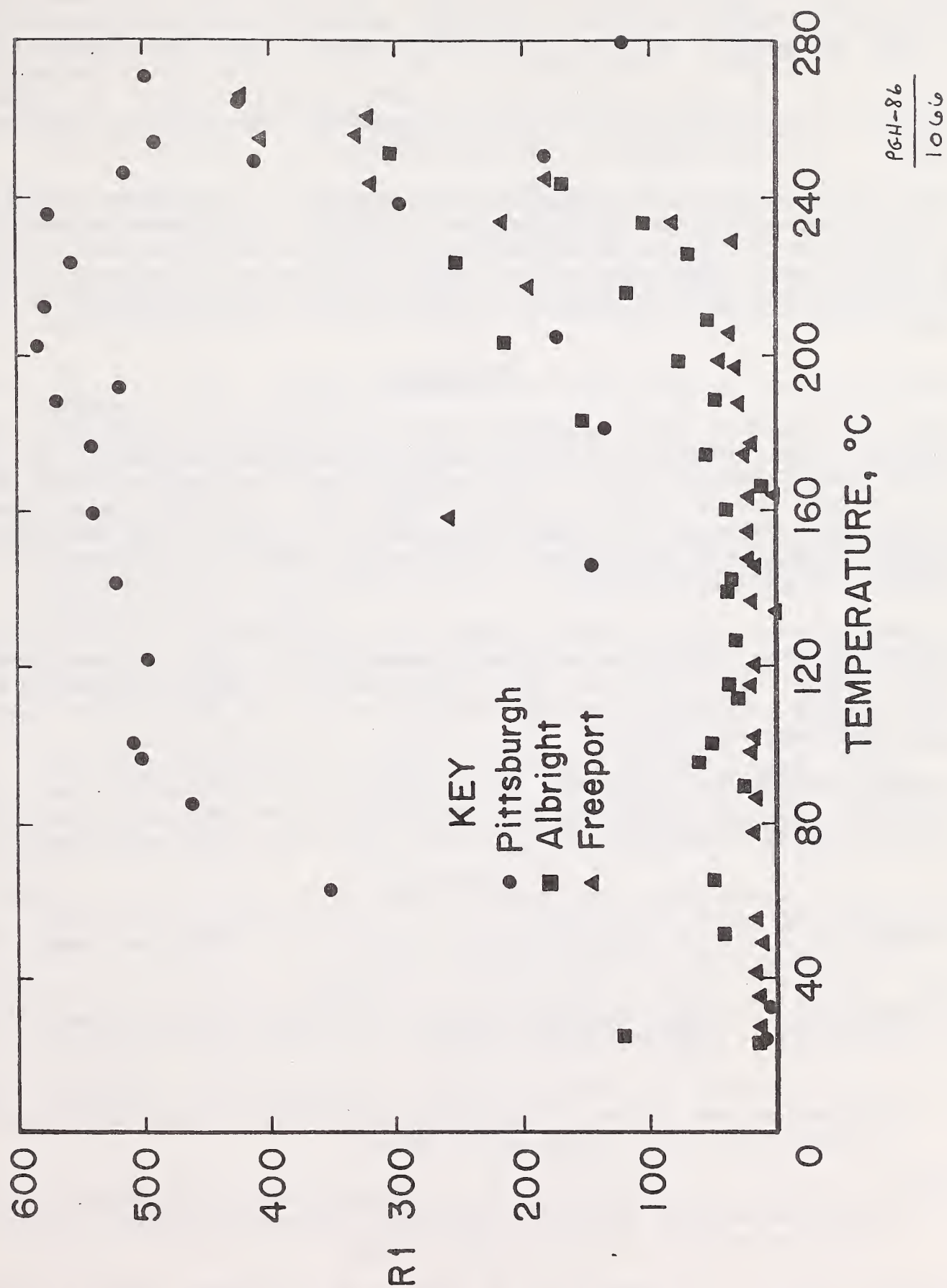


Figure 11. Variations in mean hydrocarbon ratios with temperature.

Limited analyses were performed on other possible combustion indicators such as JTR and CO_2/CO ratio. For the JTR, there were two problems. First, compressed breathing air which was used in portions of these tests had an oxygen concentration greater than that of normal air. The excess oxygen introduced an error in the calculation of the JTR when using the equation given. Also, in later portions of the tests, excess nitrogen was used to suppress the tendency of the samples to self-heat, which affected the calculation of the oxygen deficiency and the JTR.

In a first appraisal of the CO_2/CO ratio, there was no significant correlation between temperature and the airfree ratio CO_2/CO . Since these are oxidation products, the changes in the concentration of oxygen could have had an effect on these values. More extended data analysis is required to determine if there is a relationship between JTR and airfree CO_2/CO and temperature in these tests.

SUMMARY

From the laboratory tests completed to date, the calculated hydrocarbon ratio (R_1) is a good indicator of heated coal. Preliminary analysis of the data indicates that absolute numbers are less significant than changes in the value R_1 . In other words, if R_1 is plotted versus time, a positive slope indicates increasing temperature; a negative slope indicates cooling. The variations in R_1 may be related to differences in adsorbed gas content or differences in the internal pore structure of coal.

It seems probable that in field situations the determination of R_1 values during borehole suction testing can be used to establish the limits of heated underground zones. Also, since at a given temperature, R_1 does not have the same value during heating and cooling, changes in R_1 with time can be used to monitor fire control projects.

Further tests in this series will be performed on four bituminous coals, one anthracite, and an anthracite waste in order to generate significant background data for a comparison with field data from various fire control projects.

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USE OF FOAMING MUD CEMENT TO TERMINATE UNDERGROUND COAL FIRES

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Abstract

Terminating underground coal fires is difficult and often ineffective. Trenching, backfilling, compacted overfill, application of water, and other techniques are generally costly and are commonly not effective in extinguishing fires. These techniques generally attempt to either cut off the oxygen supply or to reduce the temperature of the burning coal, but rarely do existing methods attempt to accomplish both control techniques at the same time. Foaming mud cement (FMC) has the characteristics that allow it to cut off the oxygen supply to the coal, reduce the temperature of the burning coal, and provide roof support to prevent subsidence of the burned cavity.

FMC is a slurry that contains Portland cement, soil, water, and nontoxic admixtures for expansion and modification of physical characteristics. Research has shown that a wide variety of soils can be used to formulate FMC and that other materials, such as river sand, mine tailings, and similar types of localized waste products, can be substituted for soil. Various parameters of FMC, including viscosity, specific gravity, pumpability, delayed expansion, and strength, can be modified to meet the requirements of specific mine fires.

At the Colorado School of Mines Research Institute, chambers ranging in size from 1/10 to 1/2 scale were constructed to simulate underground cavities. The chambers were partially filled with coal and the coal ignited and allowed to burn until coal bed temperatures exceeded 1800°F. Thermocouples were placed in various portions of the burning chamber and FMC applied. Immediately after application of FMC, coal bed temperatures decreased to approximately 200°F. Excavation of the remnant coal demonstrated that FMC effectively encapsulated the coal particles, thus excluding oxygen and rapidly lowering the temperature well below the combustion point. Upon setting, the FMC became cellular concrete with sufficient compressive strength for subsidence control of burned out cavities.

The research conducted to date indicates the FMC is an excellent product for extinguishing underground coal fires and providing subsidence control. This product also appears well suited for control of small coal fires that are commonly ignited during surface coal mining.

HIGH PRESSURE WATER JET UNDERGROUND COAL FIRE EXTINGUISHING RESEARCH

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Synopsis

A five-foot high coal seam is burning on the bank of the Yellowstone River near Sidney, Montana. A novel method was used to examine the ability of the high pressure water jets to extinguish coal fires. Special equipment was built for horizontal and vertical approach and used for gathering necessary data for evaluation.

INTRODUCTION

In July of 1985, the University of Missouri (UMR) entered into a contract with the Department of State Lands (DSL) of the State of Montana, funded in turn by the Abandoned Mine Lands (AML) of the U.S. Office of Surface Mining.

The objective of this contract was to examine novel methods for extinguishing coal fires, based upon UMR experience with the use of high pressure water jet as an excavation tool. The contract also included inert injection, under either fluid or explosive pressure as a means of inhibiting the fire restarting.

A crew from UMR, the Rock Mechanics and Explosives Research Center (RMERC), reached the burning coal site in Montana on the 13th of August, 1985 to conduct a series of tests with a specially designed and machined drilling device.

LOCATION AND GEOLOGIC CONDITIONS AT THE SITE

The experimental site for this project is situated on the right (east) bank of the Yellowstone River in Sections 6 and 7, Township 20 North, Range 59 East in Richland, County, east-central Montana. This area is shown on a portion of each of the Piche and Crane, Montana 7- $\frac{1}{2}$ minute series U.S. Geological Survey topographic maps. Access to the site is via improved and unimproved roads east of the river and south of the city of Sidney, Montana.

The experimental site is composed of approximately 2000 linear feet of the face of the right bank of the Yellowstone River starting at the Shadwell Creek confluence and continuing downstream in a northwesterly direction. The surface property is privately owned and permission has been acquired to have access to this surface and make needed borings, excavations and other modifications as might become necessary.

The major portion of the experimental work took place in an area bounded on the southwest by the Yellowstone River, on the east and southeast by Shadwell Creek and on the northwest by a hill of terrace gravels and sand. This experimental area is a relatively flat surface and the overburden averages 25 to 30 feet thick over the upper coal seam. The upper few feet of this overburden is alluvial soil and alluvium deposited on top of the bedrock (Figure 1).

The Fort Union Formation is the bedrock unit at the site (Figure 2). This formation is divided into three members of which either the middle Lebo member or upper Tongue River member is the outcropping rock at the site. Both members have similar composition and contain coal beds. Positive identification of the member present is neither important nor easily established. The rocks consist mainly of fine grained sandstones, siltstones and shales. These lithologies are interbedded and repeated. Bedding thickness ranges from considerably less than an inch to one to two feet. The rock has been fractured by slight structural deformation and stress relief due to the river channel cut. The primary set of fractures is oriented parallel to the outcrop face or river bank.

Two coal seams are exposed in the river bank outcrop. The upper seam is three feet thick and separated from the lower seam by three feet of interburden. The Yellowstone River flows at a stage within the bounds of the lower seam most of the year. The Montana coal seam properties according to UMR coal lab analysis are presented in Table 1.

Table 1. Montana coal seam properties.

	Upper Seam	Lower Seam
Air-dried moisture	06.66%	8.20%
Residual moisture	18.40%	24.80%
Total moisture	23.84%	30.97%
Ash	11.47% (dry)	6.22% (dry)
Sulfur	0.91% (dry)	0.76% (dry)
Btu/lb	9103.0 (dry)	10500.0 (dry)

The geological engineering considerations of significance may be summarized as follows. Fractures in the ground parallel to the outcrop face have many impacts on the project. Slope stability is controlled, to a large extent, by these fractures. Movement of fluids within the ground is influenced by these fractures. Regional data indicate that permeability in the direction of the fractures is ten times greater than is normal to the fracture direction. Ventilation of the burning zones is accomplished through these fractures. Drilling capability is influenced by these.

THE STATE OF THE FIRE

The fire appears to spread in two phases. In the first phase, the exposed coal is ignited at a point, and this flame front grows to full seam section and moves down the face. Concurrently, it is burning into the face, and at the

Formation	Thickness	Graphic Column	Description
	V. Sc. 1"5'		
	2 - 3 Ft.		SOIL and ALLUVIUM (SM); gravel zones (GW-GP) maximum size cobble, mostly fine coarse pebble. The zone is loosely consolidated with a moderate angle of internal friction.
FORT UNION	Tongue River	22- 24 Ft.	SANDSTONE, yellowish gray to light gray, some red zones, fine to very fine-grained; SILTSTONE, tan to yellowish gray, some red zones, all interbedded with shales; same colors as above; All bright red and brittle where heated by coal fire. Sandstone and finer grained materials, as a whole, occur in nearly equal proportions. All vary from thin to massive, horizontal bedding, sandstone, and siltstone beds tend to be the most competent and form vertical portions of the exposure. Finer grained materials are weak and erode easily reducing support for the stronger beds. Toppling failures occur as lower, thick units are removed by erosion or burning. Vertical stress relief fractures parallel to the exposed face are suspected but confirmed only by observation of the toppling blocks. Slump failures are present. Well sorted sand, clean siltstone zones and fractured areas are porous and permeable.
		3 Ft.	COAL, black, fissile, low strength fractured and broken at the outcrop burns to red clinker. BTU 9,102/lb (Dry) Ash 11.5% (Dry) S 0.91% (Dry)
		3 Ft.	
		5-6- Ft.	COAL as above except BTU 10,500/lb (Dry) Ash 6.2% (Dry), S 0.76% (Dry) Seam mostly covered by water of Yellowstone River at time of visit, 8 Apr. 1985. Both coal seams burn to form a red, rough clinker zone of reduced volume. Reddish alteration of overburden and clinker volume are proportional to degree of burning.
		Unknown	SANDSTONE, As above (assumed but not observed on site)

Figure 2. Generalized stratigraphic section, right bank, Yellowstone River (SW $\frac{1}{4}$, Sec. 6, T20N, R59E on Crane 7 $\frac{1}{2}$ " quad, Montana). Burning Coal Seam Project--OSM/Montana AML.

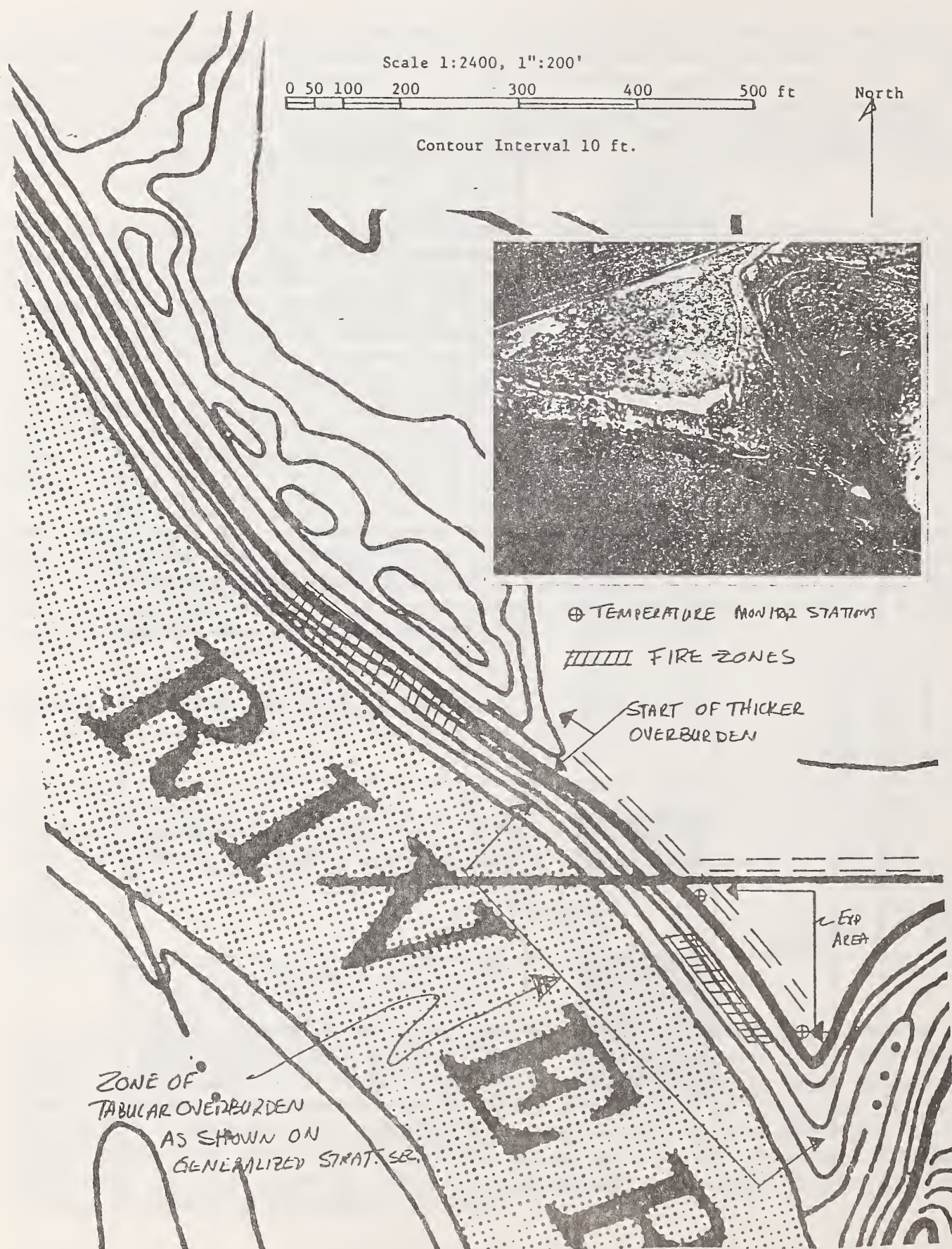


Figure 1. Shadwell Creek/Yellowstone River project site map (Crane 7½" quad, Montana).

front this flame front is roughly ten feet deep into the face. As the coal burns away it leaves a void at the bottom of a virtually vertical bank, causing the overlying material to collapse and cover the coal seam which is burning. The result is that the seam becomes completely covered, causing further burning to be partially smothered, and making location of the seam, behind a pile of broken rock and soil, a little difficult. The partial burning of the coal creates a much wider zone of burning or burnt coal, and produces levels of carbon monoxide measured in excess of 500 ppm in the vicinity of the top of the broken material and at the brow edge.

At present, the major fire lies in the upper seam, which was completely covered over almost all the test site. The edge of the river bank is continuously failing with tension cracks evident up to 6 feet back from the face as the burning coal continuously undermines the slope (Figure 3).

TECHNICAL AND THEORETICAL APPROACH

The main goal of this project was control or extinguishment of coal mine refuse pile, virgin outcrop and/or underground mine fire. Because of the dynamic nature of the problem and the vast number of attributes which had to be considered, the project is defined as one of sufficient magnitude for consideration. This is especially true because the technical and operating options for the removal, quenching and redistribution of burning materials are limited, and because of the exposure of equipment operators and technicians to hazardous conditions during implementation of currently used corrective measures. Also the high cost and public impact of those conventional extinguishment measures that create large quantities of dust involve large volumes of water and create local disturbances either of the environment or through the disruptions caused by transportation of large volumes of material.

Two different approaches have therefore been developed in order to gain access to the fire. The first of these is to drill into the face horizontally from the river side. In the second phase, holes were drilled vertically into the coal ahead of the face in order to establish a water grout line ahead of the burn and to move this curtain over into the coal, thus inhibiting the further spread of the fire while at the same time extinguishing the flame front. The mentioned ideas of using high pressure waterjets are illustrated in Figures 4 and 5. To cool down the coal seam area burning under the fire, the system of horizontal holes were drilled by high pressure water jets.

For the natural conditions, when horizontal approach is impossible the system of vertical holes to the coal seam can be created. Using the same high pressure equipment, there is a technical possibility to create chambers and slots in coal seam which make underground channels (Figure 6) which can be filled by inerts and create a barrier strong enough to stop further front fire propagation.

HIGH PRESSURE WATER JET DRILLING DEVICE AND ITS PERFORMANCE

The scheme of the machine which has been built for field trial is presented in Figure 7. The high pressure water is supplied from the high pressure pump to the rotary coupling and further to the nozzle which can rotate by hydraulic motor and advance along the tower. The large volume of water (120 gpm) is delivered through the low pressure coupling to the area between the drill pipe



Figure 3. Yellowstone River collapsing bank.

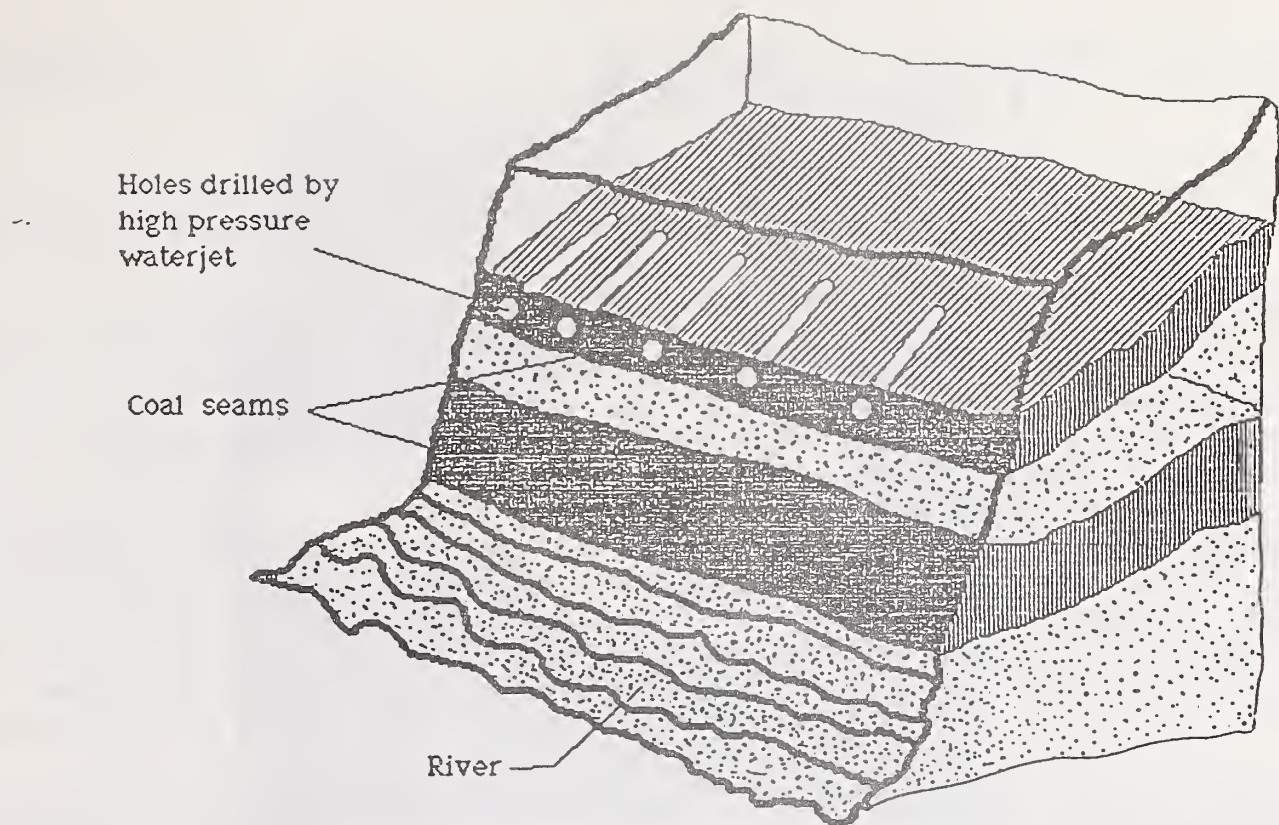


Figure 4. Horizontal channels developed by high pressure water jet.

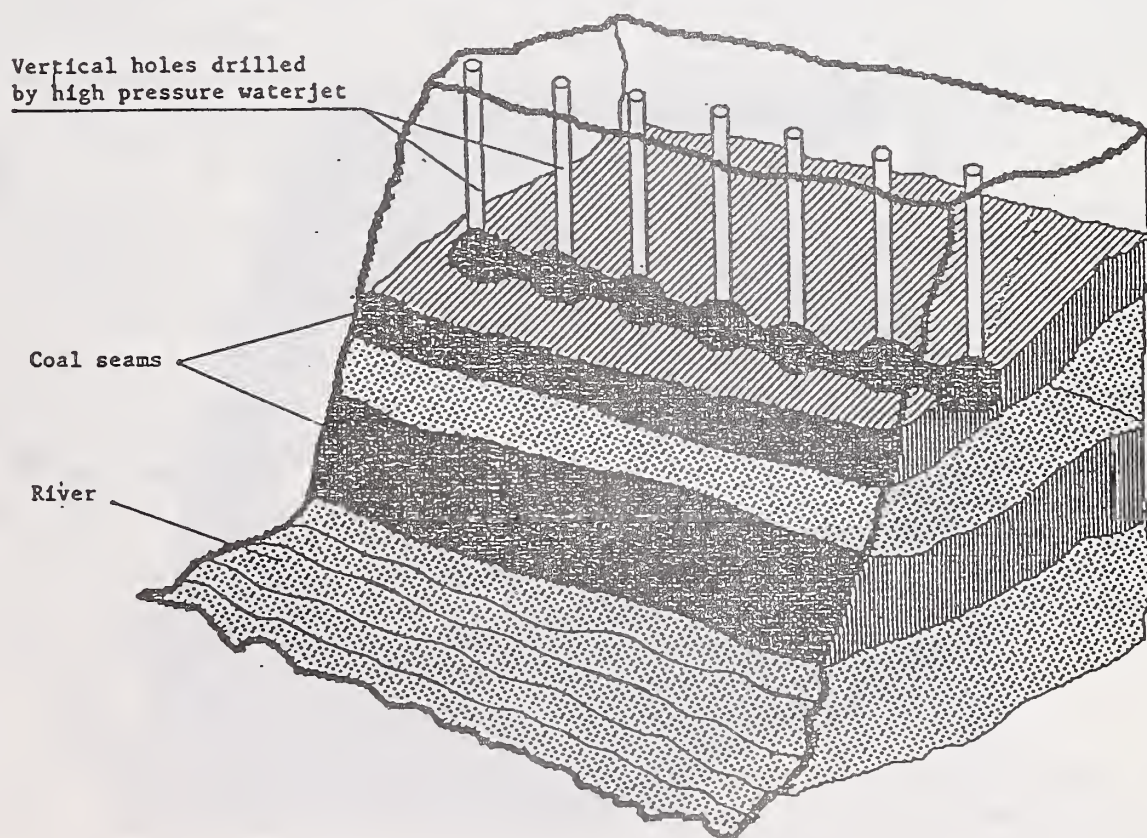


Figure 5. Barrier creation by chambering and slotting.

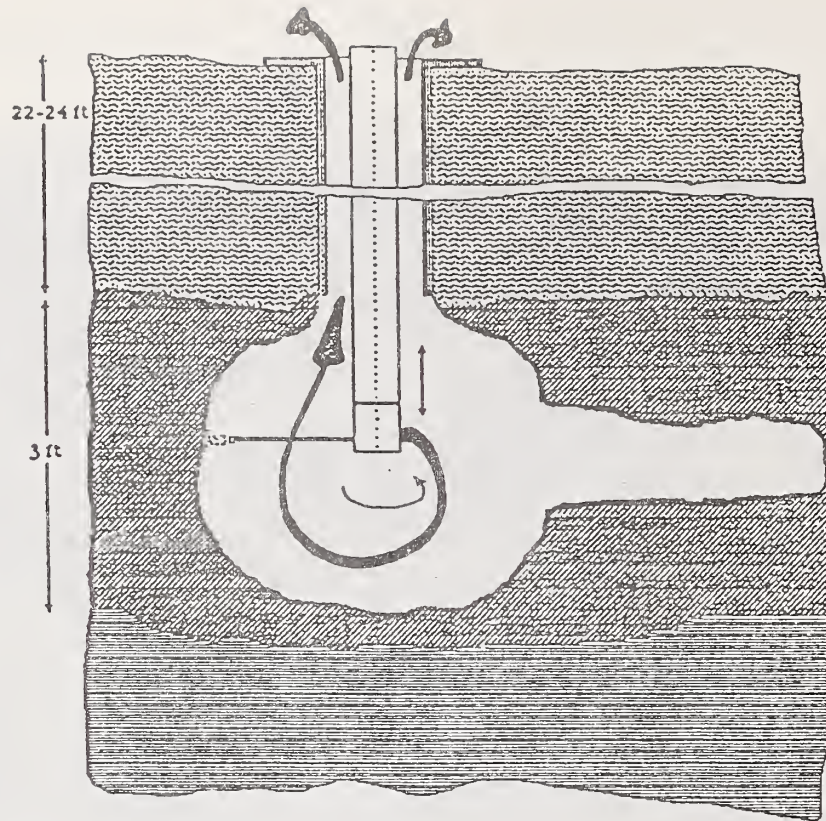


Figure 6. Chambering and slotting by high pressure water jet.



Figure 8. Drilling bit with high pressure nozzles.

and centrally located flexible hose. The outlet of the flow is located near the high pressure nozzle head for a more effective flushing of cuttings out of the hole.

Application of this drilling device designed by the RMERC team during field tests shows full efficiency during horizontal and vertical application.

To get access to the upper coal seam, we had to drill through approximately 20 feet of overburden. The first 2 to 3 feet of soil and alluvium did not present any obstacle for the high pressure water jet. The deeper layers of fine and very fine grained sandstone and siltstone were all interbedded with shales. Sandstones and siltstones in sizes of more than 4 inches were located below 13 feet and their density was considered as a significant obstacle to access the coal seam. During a series of tests with cutting head armed with two nozzles (0.040 inch) conducted for different nozzle orientation, and different drill rotation speed, axial force and with or without, big volume and low pressure flushing water, drilling below the 13-foot level was impossible. The first 13 feet was very easy to drill and time required was in a range from 10 to 12 seconds. The deeper drilling required the design of a special bit supported by the high pressure water jet (Figure 8).

The above bit was designed to push all of the stones in size above critical to the side of the drilling head and pack them laterally. Later it was checked that the hole developed was solid and did not collapse from the back and forth movement of the drilling pipe for the chambering and slotting operation. This drilling head makes it possible to cut from 13 feet to 20 feet deep in 1 minute 50 seconds to 2 minutes 30 seconds to reach the upper coal seam. During the drilling operations it has been found that the concept of using a supplied flushing water and adding an additional high volume (120 gpm) low pressure (100 psi) pump was very helpful during the drilling of the hole through the coal seam. Coal cutting was transported easily above the ground and the average cutting size was around 0.010 of an inch.

The chambering and slotting experiment was carried out by using a different cutting head presented in Figure 9. It was expected that a chamber in the coal seam could be developed by rotating the nozzle and moving it up and down. Slotting can be made by moving the cutting head up and down and rotating it in a narrow angle range. With the use of water jets, under pressure of 15,000 psi, it depended on the combined stress to cut the depth to approximately 6 to 12 inches. Based on this idea one row of vertical holes along the river bank was prepared (Figure 10) to develop an underground channel to interfere with mutual chambers or connect the underground channel from hole to hole slots. This operation was carried out and the chamber geometry was measured after uncovering this area by mechanical means (Figure 11). It was observed that the channel was created with average diameter of 18 inches along the row of the vertical holes.

TEMPERATURE CONSIDERATION AT THE FIRE FRONT

The experiments have been carried out in an exposed river bank, where two separate coal seams outcrop. Under normal conditions the coal appears to be a woody sub-bituminous coal with relatively poorly defined cleat and bedding planes.

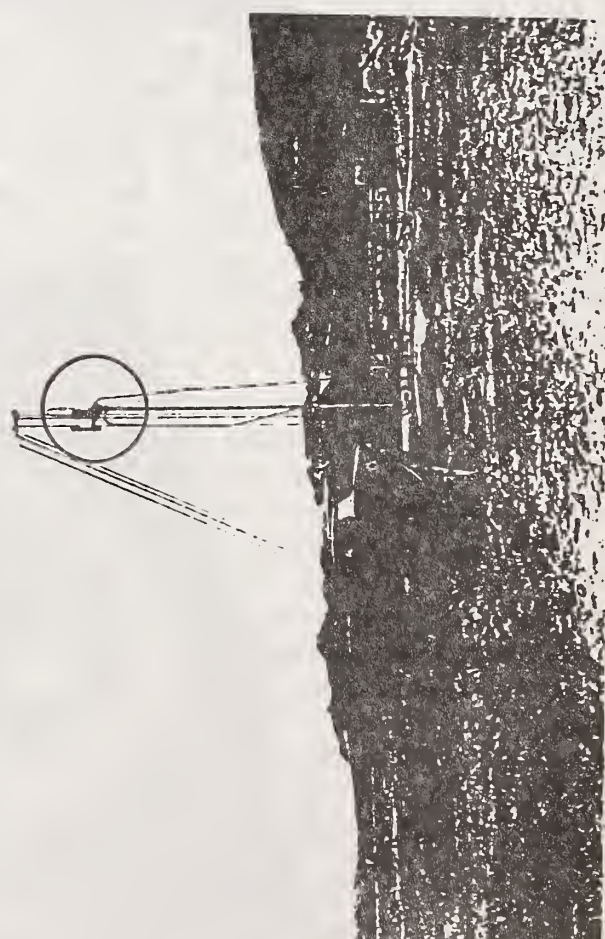
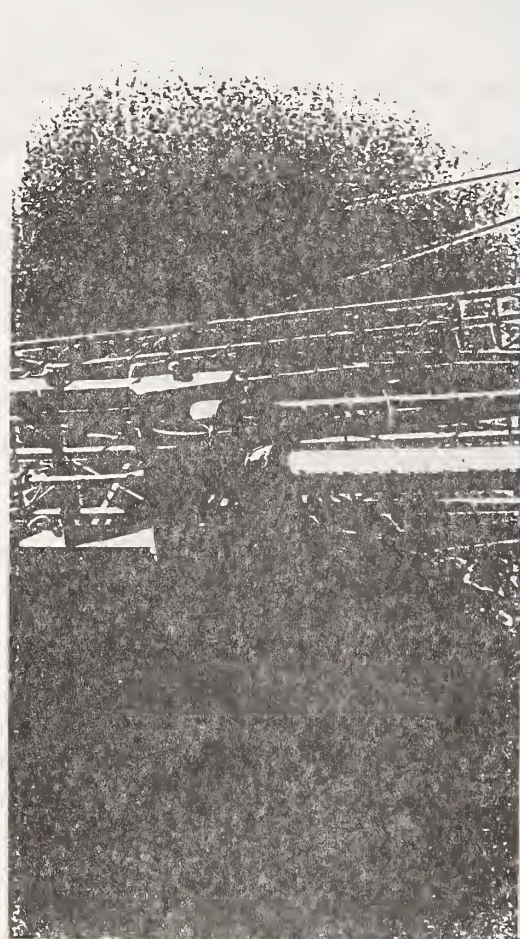
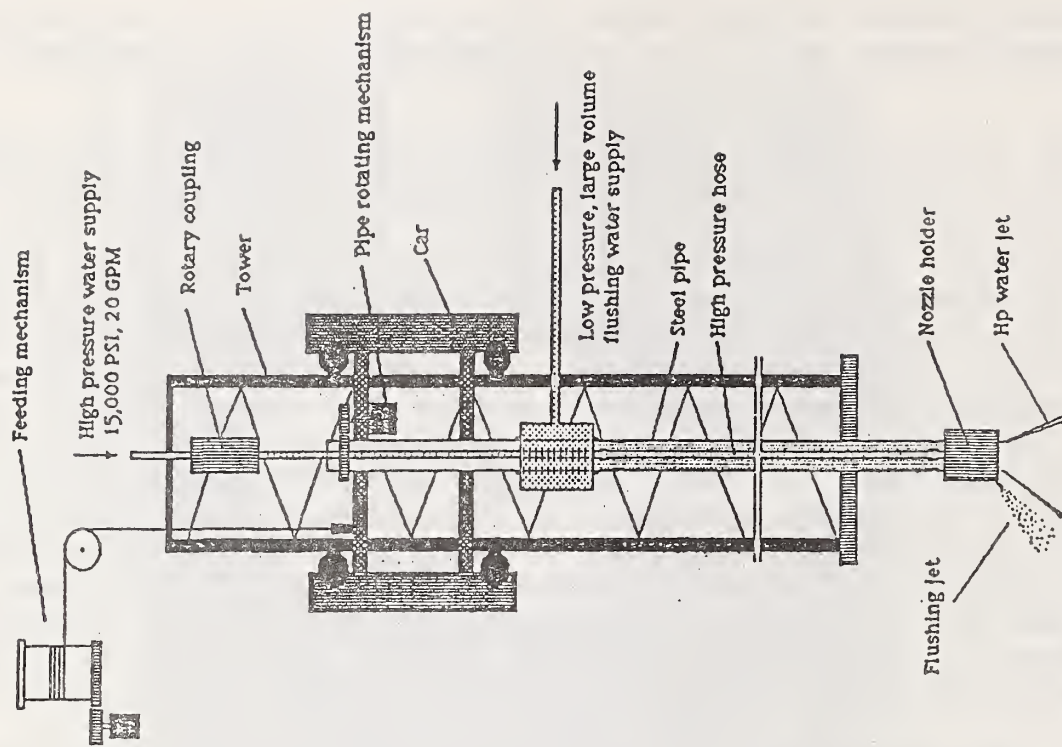


Figure 7. Scheme of drilling device.

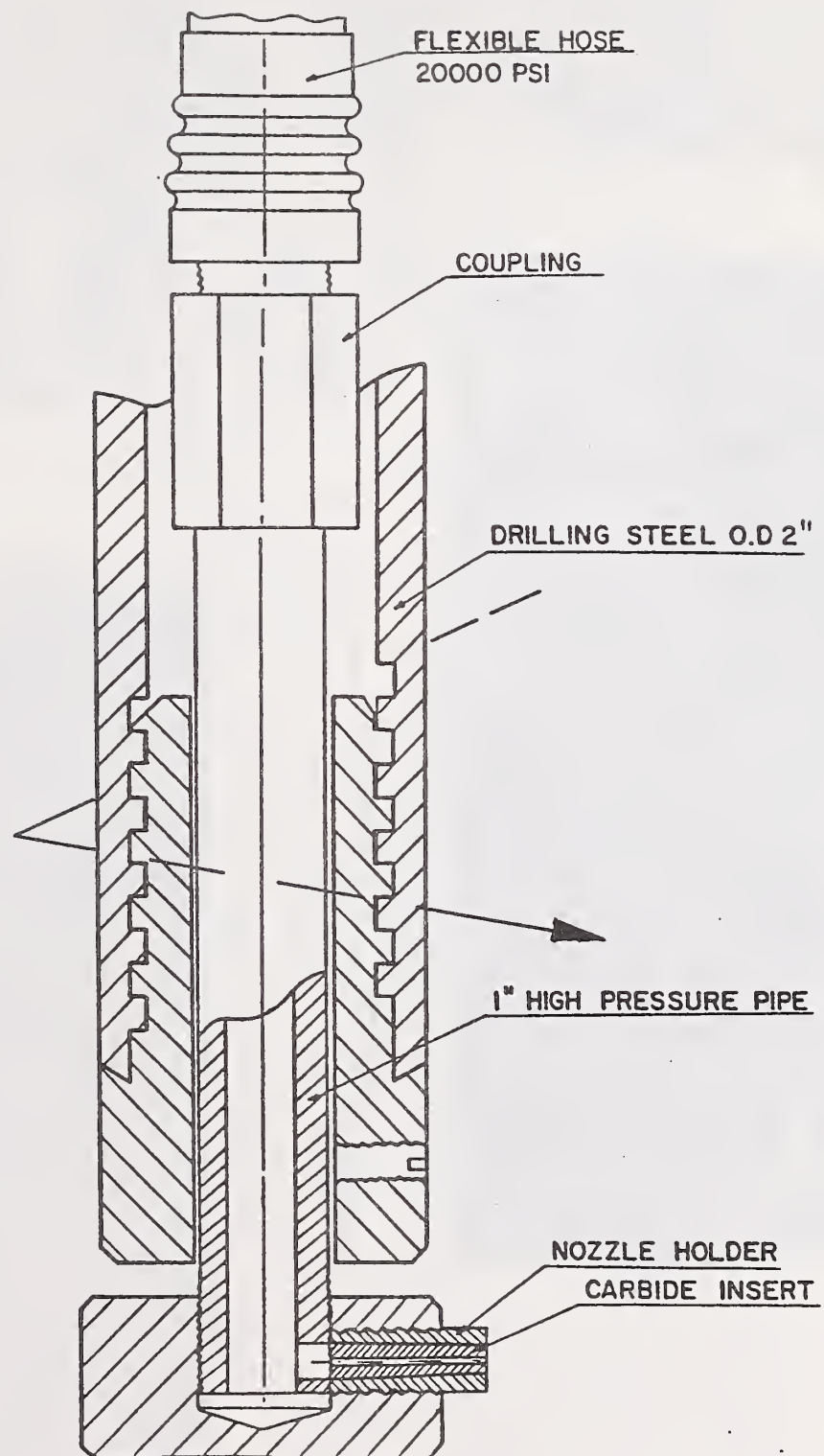


Figure 9. Angle cutting head.

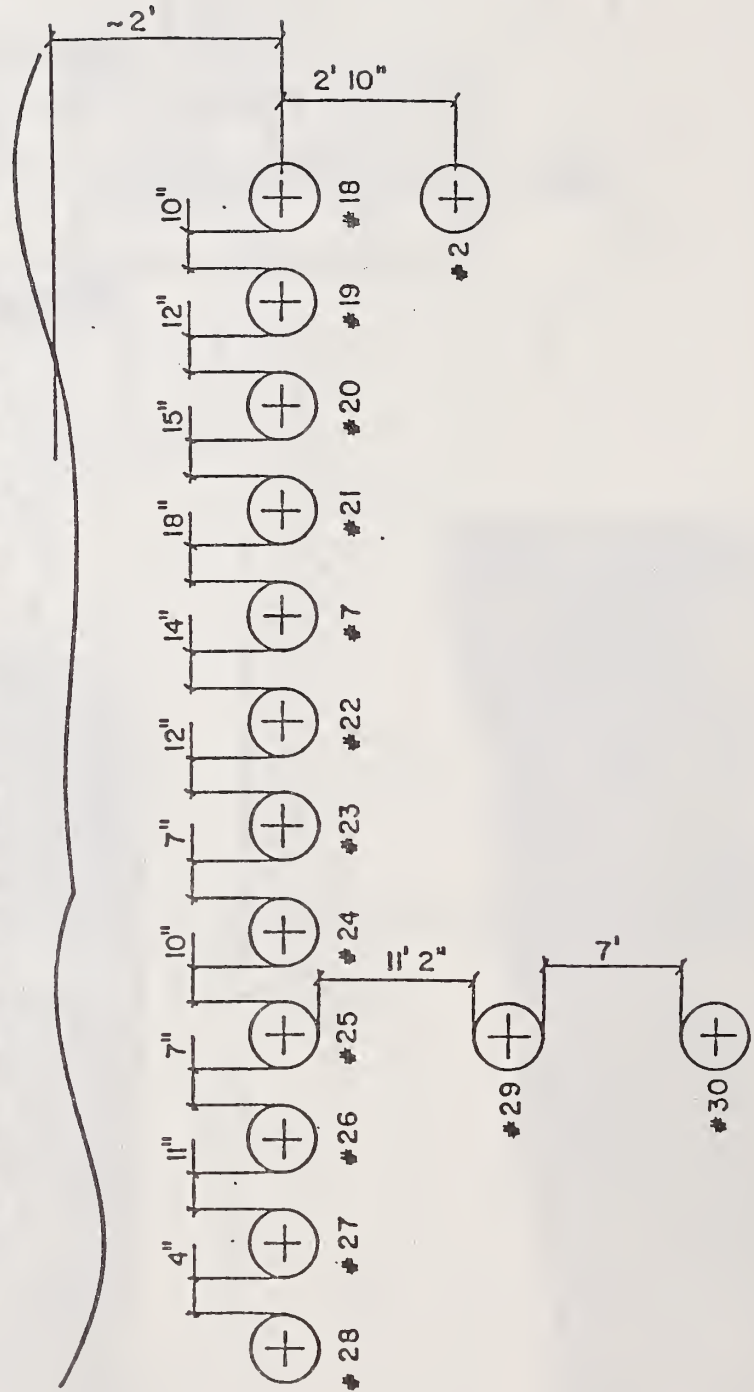
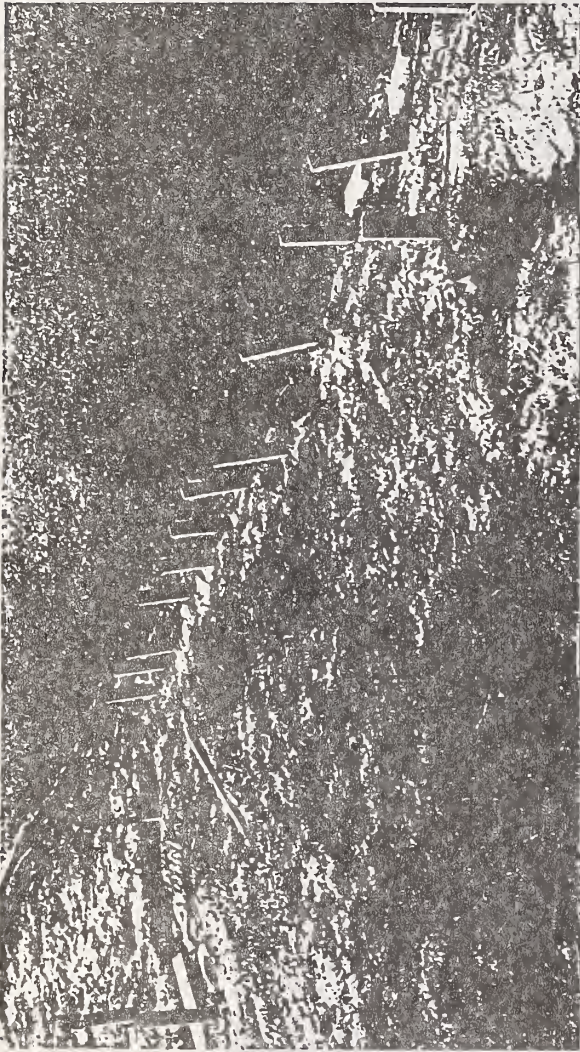


Figure 10. Vertical holes scheme for underground channel creation.

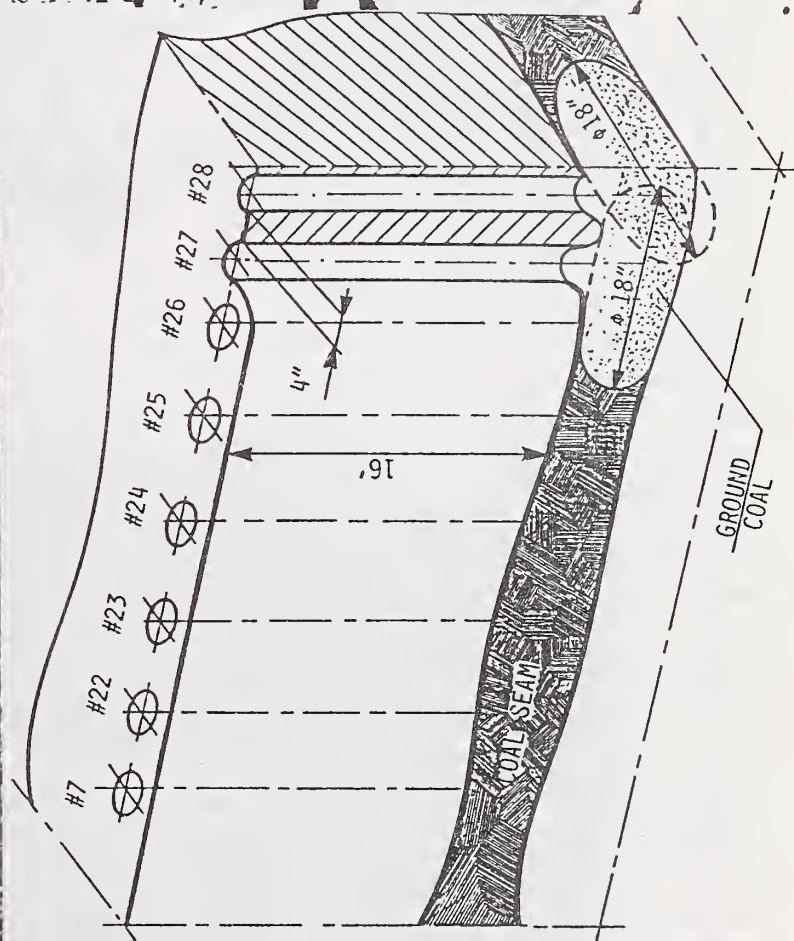
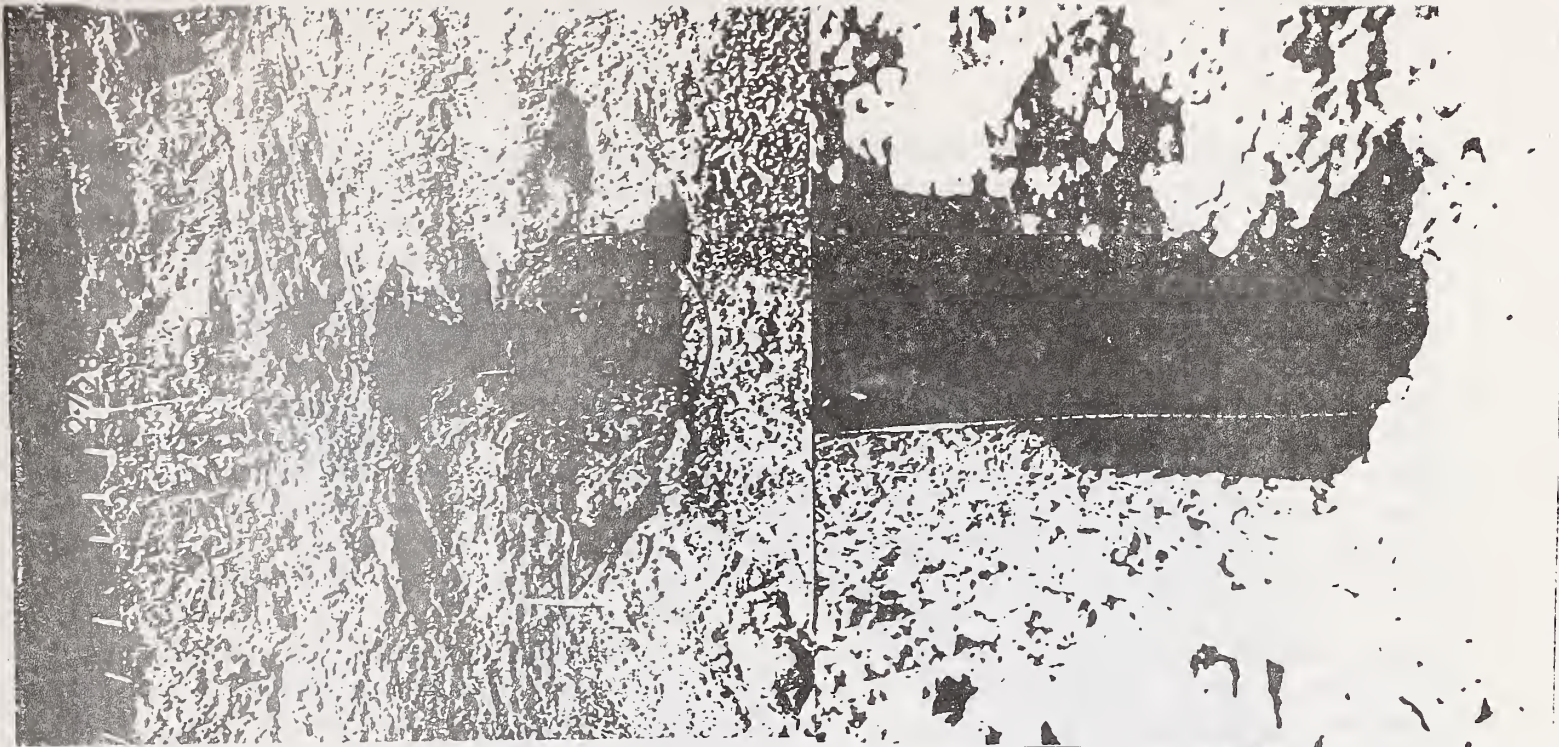


Figure 11. Chambering system schematics.

The initial problem was to identify the size and location of the fire. In order to achieve this, small holes were drilled horizontally through the fire front (Figure 12) and an array of thermocouples located at 18-inch increments down each hole. The use of a water jet drill allowed holes to be rapidly drilled through the coal and overburden, and locally extinguished the fire, so that the bearing rod for the instrumentation could be inserted into the hole (Figure 13). The holes were generally full of drill cuttings for the back portion of the hole, and the instability of the material around the opening meant that within a short period of time the hole had collapsed around the instrumentation. This meant that the instruments will reflect the local temperatures, and that there will be no greater air flow into the site as a result of the hole location. Where this was not done, and a larger hole was created, this caused the entire hole section to ignite within a short time (roughly 20 hours).

Experiments have since been carried out examining the potential for treating the fire, and it has been found practical to totally remove a 3-foot by 3-foot section of the seam in a single pass of a horizontal water jet drilling unit, within the flame front zone. Such a cavity is only stable for a short time since the overlying clay is baked by the fire and is shattered under thermal shocking when impacted by the jets. A redesign of the nozzle and provision of a means for excavating the material cut will, however, allow a sufficient volume of material to be removed, over the full seam section, as to provide a realistic fire break for the seam and lead to total extinguishment.

The following graph (Figure 14) shows the results obtained, over a two week period after installation of the array at one location, showing readings from only three of the thermocouples located along the hole. As a result of the evaluation of the conditions of the test site, and a review of the tests which were carried out, it is possible to recommend a procedure to finally extinguish the fire. It was evident that a water jet drill had no problem in drilling into burning material, with sufficient material being extinguished, provided that the drill hole was large enough to handle easy insertion of instrumentation. On the other hand, the fire was extinguished for only a short distance from the edge of the hole, and re-established itself at the hole boundary within one or two days. In order to fully extinguish the fire on a permanent basis the viable alternative is to use the water jets to remove all the coal from a sufficiently wide path in front of the fire so that the fire dies from starvation.

The recommendation to remove the entire coal section from a zone ahead of the flame front is made for several reasons. First, because the flame front is not vertical, excavating in the burning zone, while practical, does not guarantee that all the burning material will be put out. Secondly, if the slot is cut where the fire had existed at a high enough temperature to bake the overlying material, this will collapse into the hole as it shatters under thermal shock when contacted by the jet spray. This provides more material to be removed, and makes the process more difficult. Thirdly, while working in the burning zone the cutting water turns to steam after impact and does not provide enough fluidity to allow the debris from the cutting operation to be carried out of the hole.

At this time it is recommended that the fire be extinguished by using a water jet drill to excavate all the coal, over the full seam section, from a zone ahead of the burning seam. In order to achieve this purpose, the water jet drill should be assisted by additional mechanical means (Figure 15) in order to

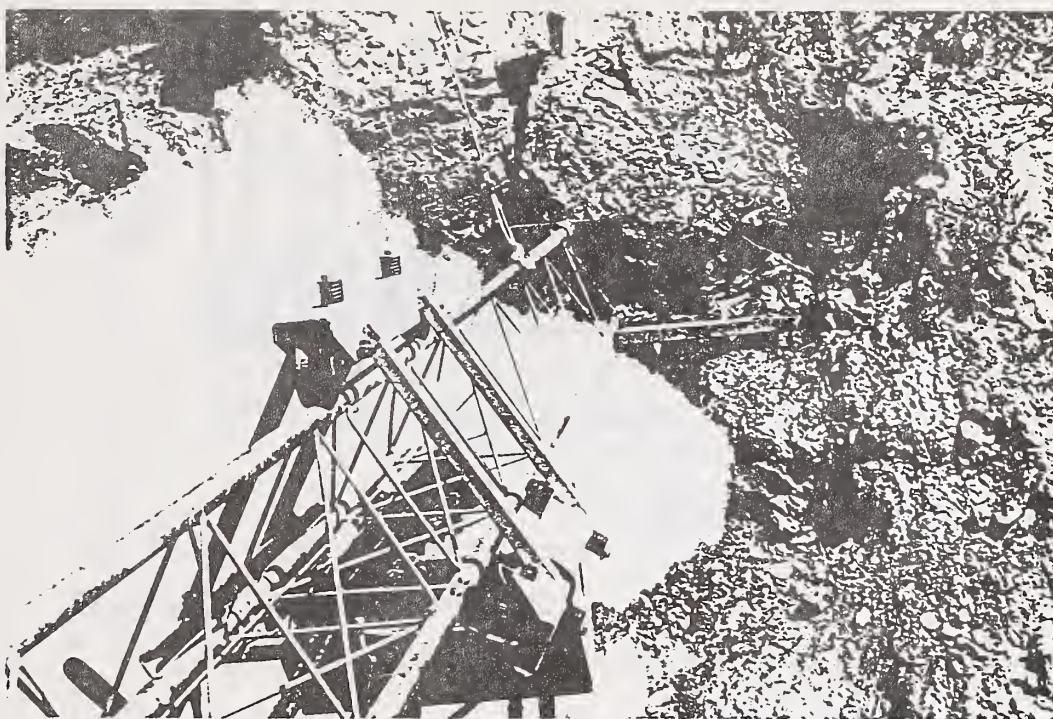


Figure 12. Drilling by water jet.

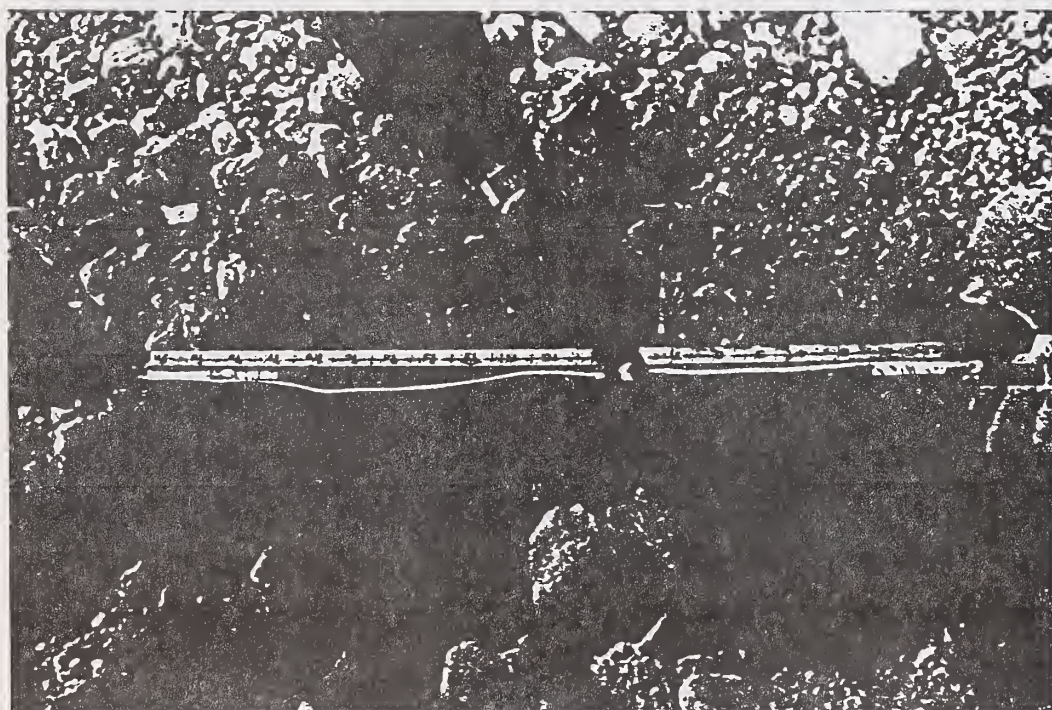


Figure 13. Steel rod with thermocouple.

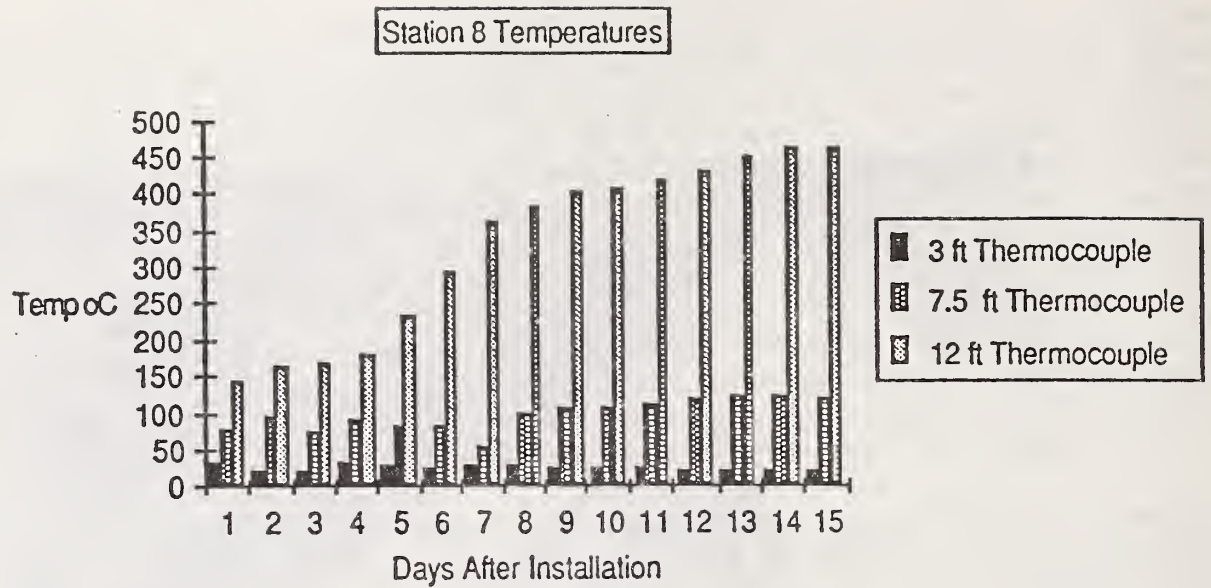


Figure 14. Temperature vs. time.

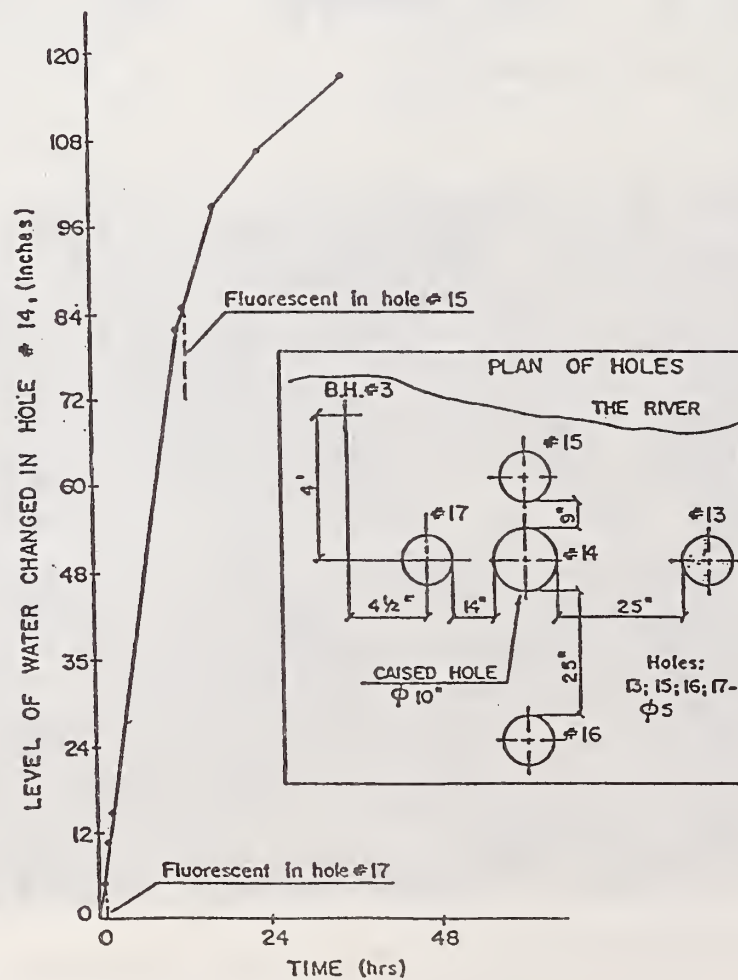


Figure 17. Scheme of the holes for permeability test and test results.

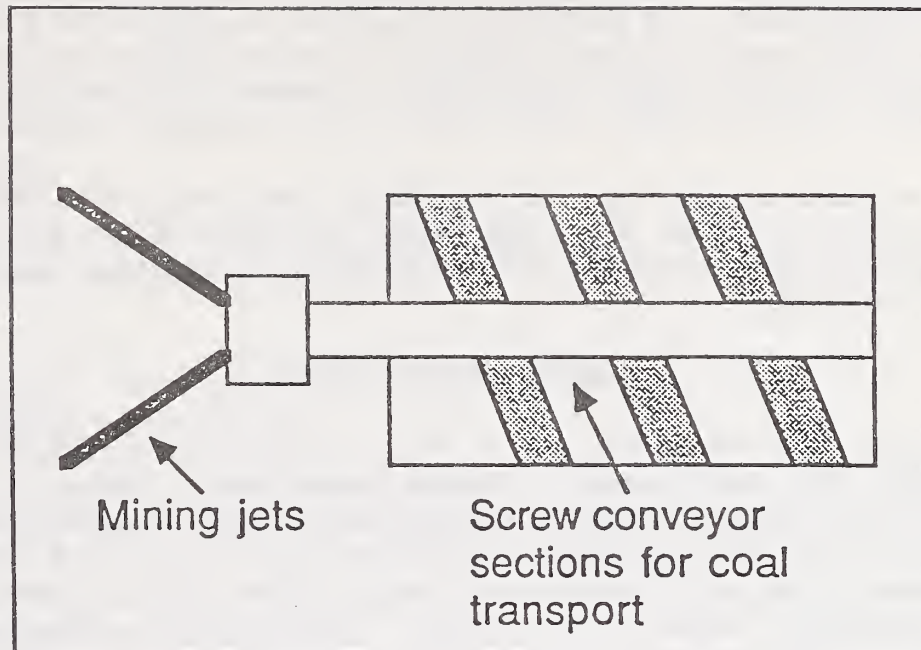


Figure 15. Excavation system schematics.

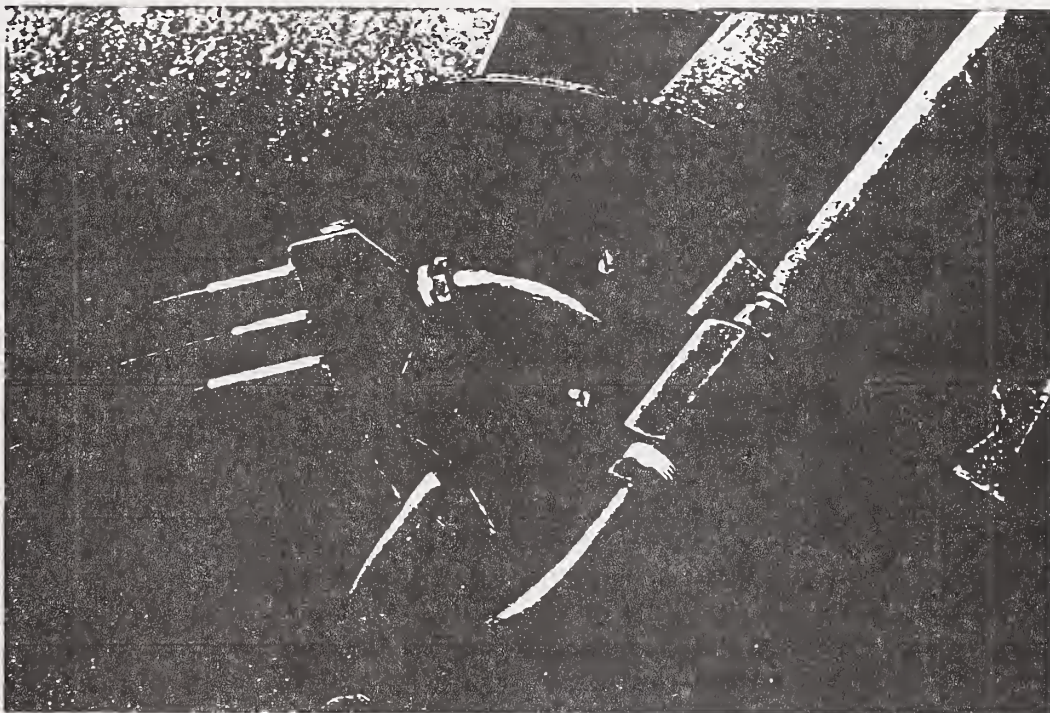


Figure 16. Screw conveyor reinforced by jets.

remove all combustible material from the slot cut, which should then be back-filled with inert material. It proved possible to cut a slot to a width of up to three-quarters of a meter in the initial trials, where the overlying material had been partially or wholly baked, and thus a barrier width of a meter, achieved with two adjacent passes of the drill should be practically attainable.

The device to achieve this type of excavation was built at UMR and the test rig is presented in Figure 16. The drill is followed by a screw conveyor section which is used to remove the coal from the cutting zone as the drill advances into the face.

PERMEABILITY TEST

Permeability test was conducted on a set of mechanically drilled holes to the upper coal seam and were cored. Those holes were originated near to bank edge (Figure 17). After hole preparation, the bottom of every hole filled with ground water. The central hole was filled with water and the water level changes was measured as a function of time. There was no water level change in the surrounding holes. To deduct permeability Flourescein Sodium ($C_{20}H_{110}Na_2O_5$) salt was used to find time of penetration from the central hole to other ones in perpendicular and parallel direction with respect to the bank edge line. The result of this measurement is presented in Figure 16. It has been estimated that permeability along the bank is about 10 times larger than perpendicular to the bank.

CONCLUSIONS

The project carried out is very complex and the results achieved should be verified by extended hole drilling experiments. Based on the test results, the following conclusions can be drawn for horizontal and vertical approach.

Horizontal Approach

- It is evident that the water jet drill had no problem drilling into the burning coal seam with sufficient material being extinguished.
- Drilled holes provide better oxygen access to coal seam and helps to re-establish fire.
- Holes created are very collapsible due to the burned overlying material properties.
- The high temperature at the fire outcrop during water action produces an affect similar to a small explosion, which helps to create a new chimney and ventilation helping the fire survive.
- The depth of the fire front is about 10 feet from the bank.
- The maximum temperature recorded during the test was 1500°C.
- Burning coal impacted by a jet produces carbon monoxide which is dangerous to the operators. Operators should be protected.

- The mechanical solution applied for horizontal drilling performed very well. After a refining for professional use, such a drilling device could be available to rapidly address future emergency situations or can be applied to long-term problems of significant environmental impact.

Vertical Approach

- Vertical hole drilling device was successful. In the future, it will be necessary to use additional mechanism for controlling the drill bar feed rate.
- High pressure jet should assist regular cutting bit in the case of solid rock or highly dense rock.
- Simultaneous casing operation during high pressure jet drilling was successful only to the depth where siltstone and sandstone occurred.
- The ability of the jet to create an underground channel in the coal seam proved successful.

General Remarks

- Tests proved that permeability along river banks is around 10 times larger than in parallel to the bank. This fact can be utilized in future approaches.
- Based on experience in the drilling machine concept, the around-the-corner drilling machine should be taken into consideration for future research.
- Vertical holes are easier to protect from oxygen access to the coal seam than horizontal holes.

ACKNOWLEDGEMENTS

This program was funded through the Montana Department of State Lands and we are grateful to Mr. Juntunen of DSL for the considerable help which he and his organization provided. Paul Marcus of the Abandoned Mine Land Program of the U.S. Office of Surface Mining also provided considerable help to this program, and this is appreciated. The work was carried out on property owned by Mr. Leland and Mr. Balduke, to whom we tender our thanks. For all UMR people involved in this project and provided invaluable advice and assistance in performing the work carried out in this program, their help is greatly appreciated.

APPLICATION OF TIME DOMAIN REFLECTOMETRY TO SUBSIDENCE MONITORING

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INTRODUCTION

Time Domain Reflectometry (TDR) is an electrical pulse testing technique originally developed to locate breaks in power transmission lines. In the past decade, this technique has been adapted to monitor the movement of rock masses during mining. Monitoring of the rock mass is performed by placing coaxial cables in drill holes and anchoring them to the rock mass with an expansive cement grout. Strains and breaks along the coaxial cable are generated by rock mass deformation, strata separation and large block movements caused by the subsiding bedrock. The strains and breaks produce changes in the cable which reflect electrical pulses used during the monitoring of the cable. Rock mass movements are determined by monitoring the changes in the TDR reflections.

The long-term objectives of our work are to evaluate the use of TDR as an inexpensive technique for monitoring subsidence over abandoned and active mines. TDR cables are less expensive, faster and easier to install than rod or wire-type, multiple-position borehole extensometers. The data acquisition unit is portable, lightweight, simple to use and produces a permanent record of each reading.

Members of Northwestern University are performing laboratory determinations of the type of electrical pulses generated by various deformations of the coaxial cable. They also assisted members of the Illinois State Geological Survey in performing the field site selections, installation and initial monitoring. The TDR cables were installed in conjunction with multiple-position borehole extensometers and deep observation water wells installed by the Illinois Mine Subsidence Research Program. The combination of projects at one location will allow us to better document the rock mass movements affecting the coaxial cables. Another part of the TDR study will involve the installation of a TDR cable in an area over an abandoned coal mine that is subsiding.

BACKGROUND

The TDR installation consists of a crimped coaxial cable placed in a borehole and anchored to the surrounding rock mass by an expansive grout. A TDR cable tester sends ultra-fast rise time voltage pulses down the cable from the tester. Cable defects such as crimps (a constriction causing a change in the distance between the inside and outside conductors), short circuits or breaks return these voltage pulses back to the cable tester. The returned voltage appears as a step-up or step-down transition on the cable tester display as shown in Figure 1. Faults in the cable with higher resistance than that of the cable (such as a cable fray or cut) produce a step-up signal. Faults with

lower resistance than that of the cable (such as a short circuit or crimp) will produce a step-down signal. The distance to the cable fault is proportional to the elapsed time between initiation of the voltage pulse and arrival of the returned voltage. The cable tester displays this time in units of distance.

As shown in Figure 1, there is a clear distinction between the types of cable deformations. This provides a means to improve the accuracy of estimating the distance to a deformation. The accuracy of the tester is calculated as 2% of the distance from the tester to the cable deformation. If crimps are made in the cable at selected intervals, a set of reference marks appears on the signal each time the cable is tested. The location of deformations in the cable can then be determined with respect to these reference marks. This greatly reduced the magnitude of error (2% x distance from a reference mark).

PREVIOUS MONITORING USES

The TDR cable installations have been used to monitor rock mass movements for a coal strip mine operation (Dowding 1983), a block caving mine (Panek and Tesch 1980), longwall coal mining operations (Wade and Conroy 1980; O'Rourke et al. 1982), and a room-and-pillar coal mine (Clugh, pers. comm.).

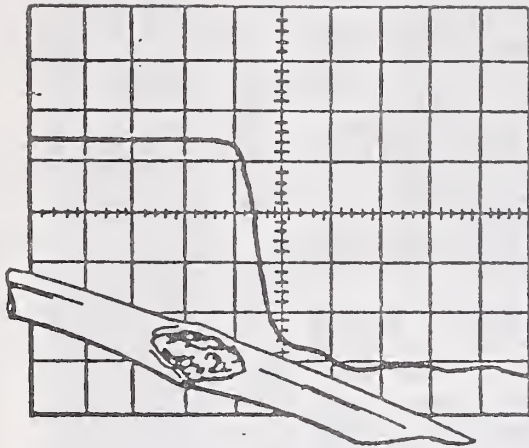
The amount of movement needed to influence the TDR cables was measured during two of these studies. The block caving mine had a TDR cable grouted to the corner of an entryway in the mine. They reported that no TDR reflections were produced when cracks in the grout had apertures of 0.12 inches or less. Panek and Tesch (1980) used a ½-inch cable with a central solid copper conductor and another conductor of aluminum. O'Rourke et al. (1982) monitored rock mass movements using a rod extensometer arrangement. They found that major cable damage occurred when strata separations totaled 0.11 inches between extensometer anchors 99 feet apart.

CABLE GROUT RECOMMENDATIONS

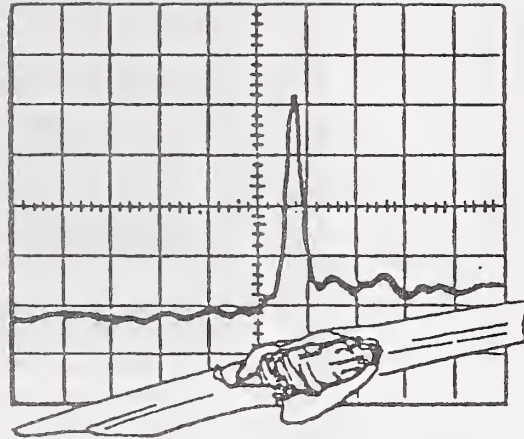
Dr. Charles Dowding, Miao-Bin Su, and Kevin O'Connor of Northwestern University have performed the laboratory testing of the strength and electrical properties of the various cable sizes and types along with testing the strength of grout mixes and bonding strength to the various cables. Results of their initial work (Dowding et al. 1986) produced specifications for the cable type and grout mix used for the first installation. They recommended a ½-inch foamflex cable with a copper-clad aluminum-center conductor, low-loss cellular polyethylene foam dielectric and smooth wall aluminum outer conductor without a protective jacket. The recommended grout mix used was Portland Type III, high early strength cement, mixed with 65% water-to-cement ratio, and 2% expansive agent (Intrusion Aide from Intrusion Repakt, Inc.).

FIELD SITE DESCRIPTION

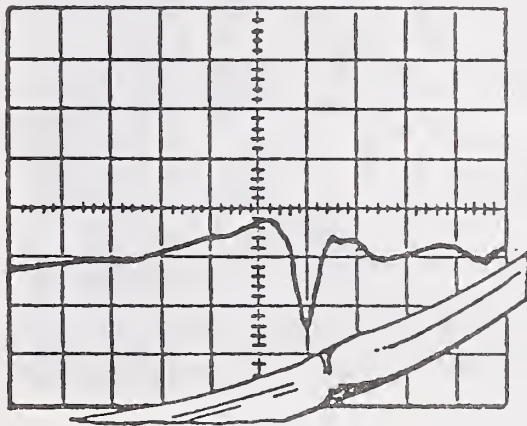
The TDR cable was installed at a site in southern Illinois, in Williamson County, over one panel of a high-extraction retreat mining operation. Figure 2 shows a typical plan of a high-extraction mining operation. This system defined a panel with entryways. On retreat within the panel, several rows of rooms and pillars are formed and removed before further retreat to form the next several rows of rooms and pillars.



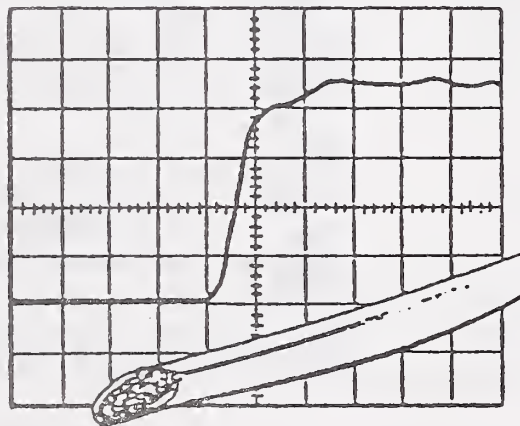
FRAYED CABLE - NO SHORT



FRAYED CABLE - SHORT BETWEEN
INSIDE AND OUTSIDE CONDUCTORS



CABLE CRIMP



SEVERED CABLE

Figure 1. Types of cable deformations and associated generated signal.

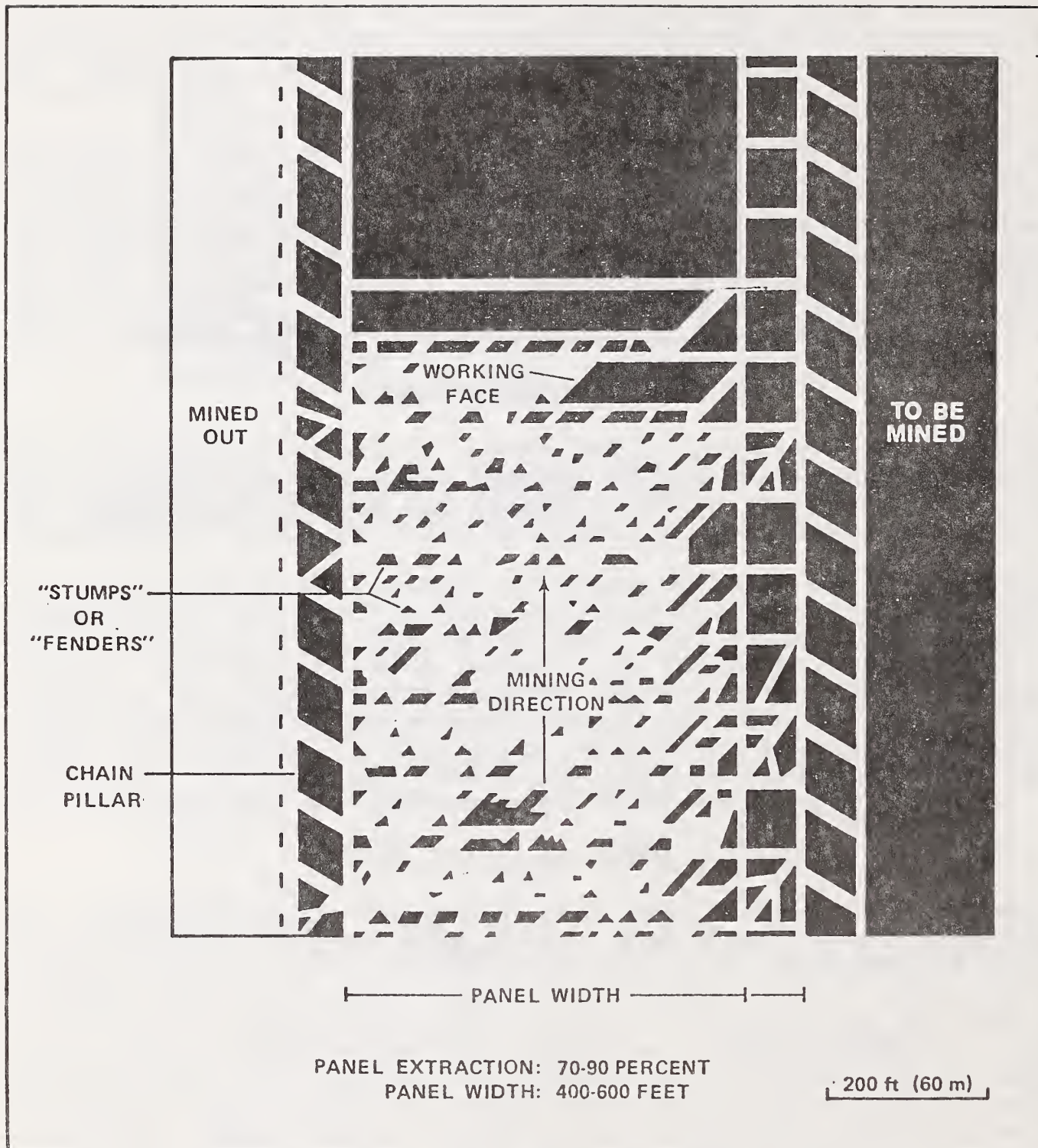


Figure 2. Plan view of a high-extraction coal mining operation. Black areas are coal.

The Williamson County mine is operating in the Herrin (No. 6) Coal seam located about 250 feet below the ground surface at the instrumented site. The coal seam is about 6 feet thick. The overburden consists of about 200 feet of Pennsylvanian bedrock overlain by about 50 feet of Quaternary glacial material.

The installation of instruments at this site was funded from two separate projects. The site contains two instrument clusters (Figure 3); one near the beginning of the panel and one near the center of the panel. Both clusters contain a 6 point multiple position extensometer, two water observation wells in the bedrock overburden, 14 subsidence monuments, 5 piezometers in the glacial overburden, and a piezometer and monument off the site serving as a bench mark.

TDR INSTALLATION

The TDR cables were easy to install. The two cables required only a few days to set in place, including drilling of the borehole. After the boreholes were rotary drilled, the coaxial cable was unrolled from the spool and laid on the ground. The TDR cable tester was attached to the top part of the cable and signal quality was checked as crimps were made in the cable every 20 feet. The crimps were made with a pair of pliers. Four crimps side-by-side at each 20-foot interval produced a good quality signal. A pipe was attached to the end of the cable to serve as a weight to guide the cable as it was lowered down the borehole by hand. A hard copy of the TDR cable signal was made after the grout mix was tremied into the borehole. The top of the borehole and cable connection was covered with a locking cap, as shown in Figure 4.

PROGRESS REPORT

Retreat mining of the panel is expected to begin in October 1986. Three sets of readings for all the instrumentations will be completed before retreat mining begins. Additional sites over high-extraction retreat mines are being secured so several more TDR cables can be installed and evaluated.

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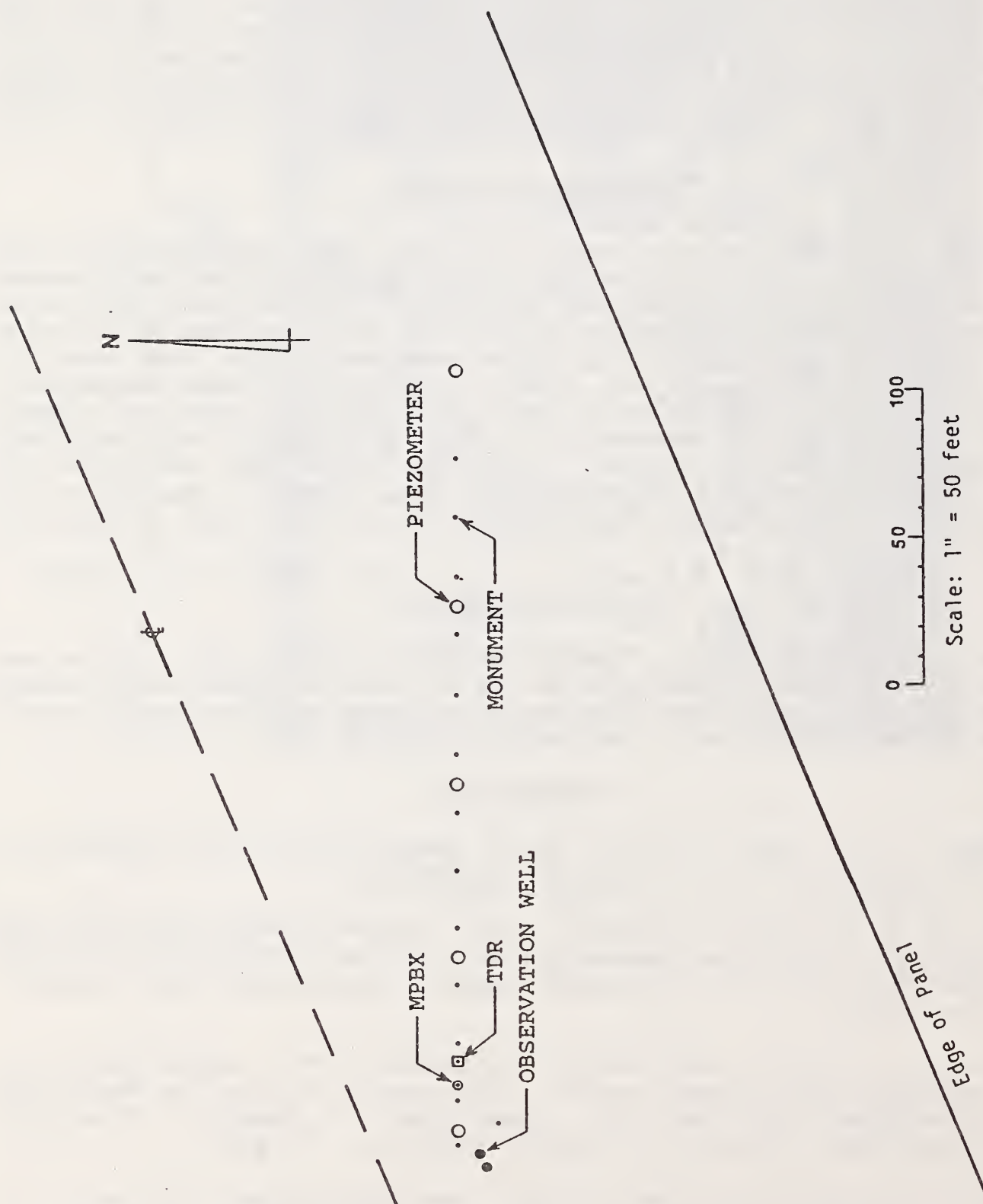


Figure 3. Example of one instrument cluster over a high extraction mining panel in Williamson County, Illinois.

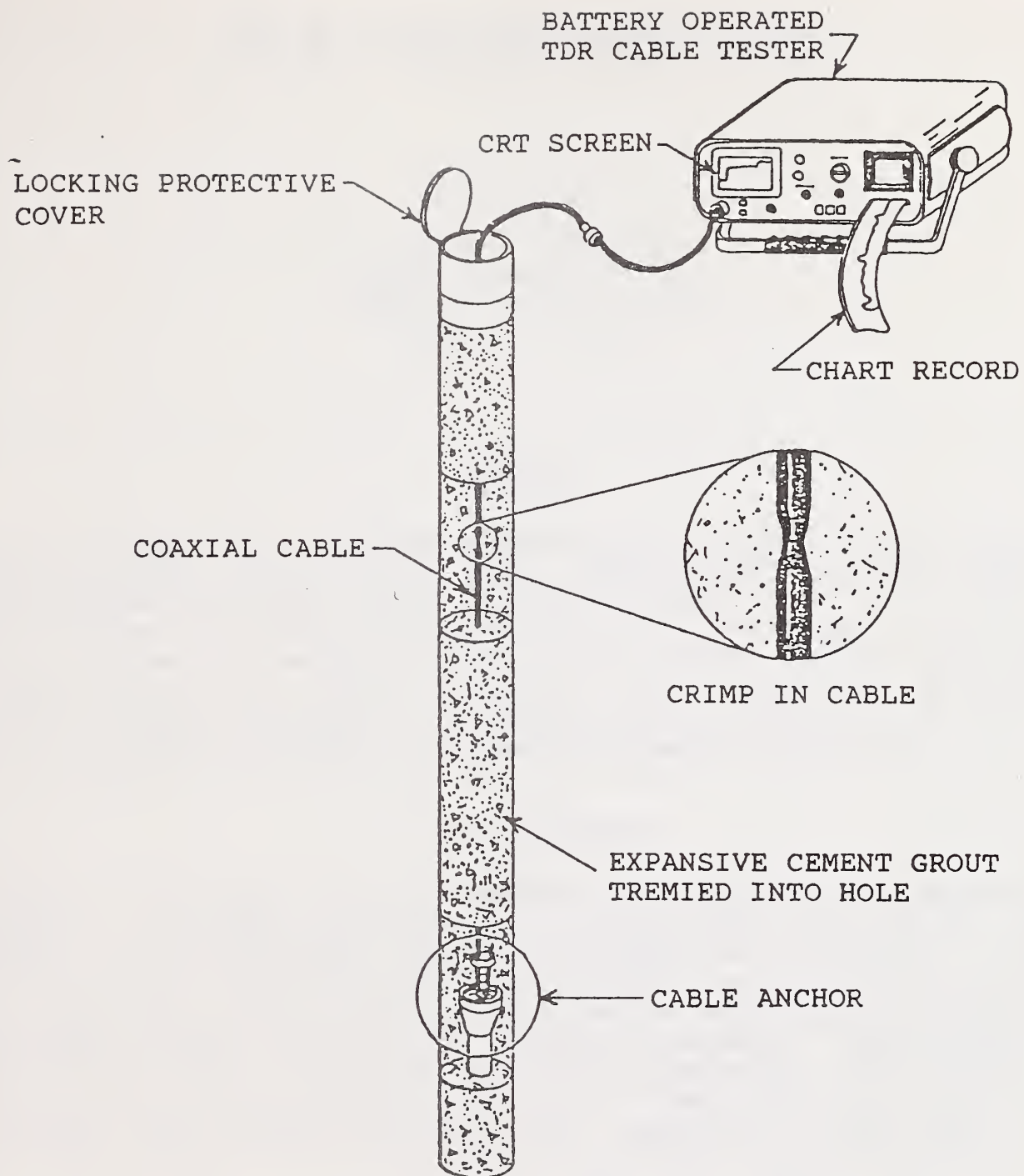


Figure 4. Schematic of a TDR installation.

USE OF SEISMIC REFLECTION METHODS TO DETECT ABANDONED MINES IN KANSAS

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Abstract

Surface collapse over abandoned subsurface coal mines continues to be a problem in many parts of the world. High-resolution P-wave reflection seismology was successfully used to locate water-filled cavities in a 1-m (3-ft) thick coal seam at depths between 9 and 13 m (29 and 43 ft) in southeastern Kansas. A dominant frequency of 275 Hz was attained enabling us to resolve both the top and bottom of the coal seam. To our knowledge, this study is the first to locate water-filled coal mine cavities at depths of less than 30 m (100 ft) using high-resolution P-wave seismic reflection techniques.

INTRODUCTION

Detection of subsurface cavities by methods other than drilling is of interest to geologists, hydrologists and engineers in many parts of the world. Recent advances in high-resolution reflection seismology are applicable to shallow cavity detection (Branham 1986; Steeples and Branham 1985). Recorded energy with dominant frequencies greater than 100 Hz is needed to detect most small shallow targets using P-wave reflection seismology. These higher than normal frequencies can be attained using non-standard seismic sources and severe low-cut analog filtering (Hunter et al. 1984; Miller et al. 1986; Miller and Steeples 1986; Steeples and Knapp 1982; Knapp and Steeples 1986a, b).

Three high-resolution seismic reflection profiles were recorded over abandoned subsurface coal mines in southeastern Kansas. The extreme contrasts of elastic properties between the coal seam and surrounding shales cause the boundaries between the two media to be excellent reflection interfaces.

PREVIOUS WORK

In the past, seismic research has been conducted to detect cavities due to salt solution mining (Cook 1965), lava flow tunnels (Watkins et al. 1967), and abandoned subsurface coal mines (Fisher 1971; Hasbrouck and Padgett 1982) with limited success. Most of the research done on coal mine detection has involved refraction seismology or S-wave reflection seismology.

Most researchers using seismic techniques for cavity detection cite three phenomena for evidence of a cavity: free oscillations or resonance of the

cavity walls, anomalous amplitude attenuations, and delay of arrival times (Cook 1965; Watkins et al. 1967; Fisher 1971). Biot (1952) found that the resonant frequency (F) of a cylindrical borehole in an infinite solid is related to the borehole diameter (D) and shear wave velocity (V_s) of the medium by the relation $D = V_s / 1.55f$. This relationship is true for a homogeneous medium, such as a basalt layer, but does not appear to be applicable in the coal mine case since the cavity is bounded by three different materials: the bottom of the cavity being composed of underclay; the sides of coal; and the roof of the overlying strata, all of which possess different elastic properties (Fisher 1971).

Cook (1965) found that seismic energy transmitted through a cavity and re-reflected from a deep horizon was attenuated correspondingly more than reflected energy missing the cavity, giving rise to a seismic amplitude "shadow". Anomalous reflection amplitudes over lava tunnels have also been observed (Watkins et al. 1967).

Due to the elastic properties of fluids, seismic shear waves will not propagate through voids or water-filled cavities, and may therefore be utilized for cavity detection. Strong SH waves have been generated and good reflections received from the tops of brine cavities 150 m (500 ft) deep (Cook 1965). Shear wave reflections have also been used to evaluate the resources of a shallow coal seam (Hasbrouck and Padgett 1982). Detection of pure S-wave reflections at depths of 10 m or less has apparently not yet been reported in the literature, and our efforts at S-wave reflection surveys at this depth have not been successful.

Seismic refraction has been used for cavity detection with limited success (Fisher 1971). In dealing with the cyclothem coals of southeast Kansas, however, the alternating shales and sandy shales yield various low velocity layers which make refraction seismology unfeasible in this area.

High-resolution P-wave reflection seismology has been used to evaluate detailed structural and stratigraphic features of a coal seam in Wyoming that is about 30 m (100 ft) thick and buried at a depth of 180 m (600 ft) (Greaves 1985). A similar study was conducted over two coal seams approximately 15 to 30 m (50 to 100 ft) thick buried at a depth of 670 m (2200 ft) in central Utah (Fry and Orange 1982). Neither of these studies, however, involved cavity detection within previously mined areas.

GEOLOGICAL SETTING

The Weir-Pittsburg coal bed in southeastern Kansas, which is the target of this study, is located within the lower portion of the Cabaniss Formation, which is part of the Pennsylvanian age Cherokee Group. The various phases of the Cherokee cyclothems are best interpreted as facies of alluvial-deltaic complexes, the repetitive nature being due to delta shifting and distributary abandonment (Heckel et al. 1979). The Cherokee coals are the culmination of aggrading sedimentation on delta plains.

The Weir-Pittsburg coal bed is the thickest of the Cherokee coals with an average thickness of 1 m (3 ft). This coal bed was extensively mined up until about 1940 by both subsurface and strip-mining methods. As a result of the subsurface and strip-mining methods, the entire area around Pittsburg, Kansas

is underlain by a maze of interconnecting cavities. Surface collapses occur in this area on the order of two dozen times per year.

THE SEISMIC METHOD

Reflection seismology involves introducing an acoustic wave into the ground by means of an artificial source, typically some form of explosion or weight drop, and the subsequent monitoring at the surface of the energy reflected from subsurface stratigraphic interfaces. This monitoring is done by means of a geophone, a velocity sensitive device which converts the ground motion from the reflected energy into a voltage whose time varying amplitude is recorded onto digital tape.

The amount of energy reflected at a given boundary is dependent upon the contrast in the acoustic impedance of the two layers, where acoustic impedance (Z) is defined as the product of the acoustic velocity (V) and the density (ρ) of each layer as $Z = (\rho V)$. The amount of energy reflected at normal incidence is determined by the reflection coefficient (R) which is defined as $R = (Z_2 - Z_1) / (Z_2 + Z_1)$; where Z_1 = acoustic impedance of upper layer and Z_2 = acoustic impedance of lower layer. Therefore, if two consecutive layers have a contrast in acoustic impedance, reflections can result.

RESOLUTION

Obtaining high resolution seismic data requires a good signal-to-noise ratio and a broad frequency band with the frequencies in a range well above those typically used in oil exploration (Greaves 1985). Since the wavelength (λ) equals the interval velocity (V_i) divided by the dominant frequency (f), [$\lambda = V_i / f$], data recorded at a higher dominant frequency will yield a shorter wavelength that is capable of resolving a thinner bed than data of lower frequencies. In order to collect data at higher than normal frequencies, an extreme low-cut filter can be applied prior to analog to digital conversion (Knapp and Steeples 1986a, b).

Knowing that the coal seam in question is approximately 1 m (3 ft) thick, the minimum frequency needed to detect the coal seam can be established. The limit of resolution is defined as the minimum thickness of a bed where the top and bottom produce effects that can be distinguished and separated (Sheriff 1980). The limit of resolution is found to be one-quarter of the wavelength of the dominant frequency (Widess 1973). The limit of detection, defined as the minimum thickness for which a seismic response can be distinguished at all, is estimated to be $\lambda/30$ (Greaves 1985). It should be pointed out that the practical limits for any data set depend on the signal-to-noise ratio and the experience and judgement of the interpreter.

Assuming an average velocity for coal of 1000 m/s and knowing the coal thickness to be about 1 m, the frequency necessary for resolution can be calculated as follows: $\lambda/4 = V_i/4f = (1000 \text{ m/s})/4f = 1 \text{ m}$. Therefore, $f = (1000 \text{ m/s} / 4(1 \text{ m})) = 250 \text{ Hz}$. This frequency has been attained in this study by use of a 340 Hz low-cut filter prior to analog to digital conversion.

SEISMIC DATA

The seismic data were collected in July of 1985 and June of 1986. Two intersecting lines were shot tying together information from three drill holes, and a third line was shot 125 m to the northeast (Figure 1). The three lines were shot using single 100 Hz geophones spaced at 0.5-m intervals. This geophone spacing produces 0.25-m intervals between CDP locations (Mayne 1962). Assuming that the mine cavities are at least 2- to 3-m across. This spacing will provide 8-12 reflection points within the cavity giving adequate horizontal resolution to detect the void. A modified 30.06 rifle was used as an energy source and the twelve-fold CDP data were recorded in the field by an Input/Output DHR 2400 24-channel recording system. A summary of the recording parameters is presented in Table 1.

Table 1. Field recording parameters.

Record Length	125 milliseconds
Sampling Interval	250 microseconds
Source	30.06 rifle
Source Interval	0.5 m (1.6 ft)
Receiver Interval	0.5 m (1.6 ft)
Receiver Array	single geophones
Geophone Frequency	100 Hz
Field Geometry	split-spread, 12-fold CDP
Near Offsets	3.25 m (11 ft)
Far Offsets	8.75 m (29 ft)
High-cut Filter	out
Low-cut Filter	340 Hz
Notch Filter	60 Hz
Anti-alias Filter	2000 Hz

Because of a surface collapse and irregular surface topography, a relative elevation survey was carried out to allow the calculation of surface static corrections. This adjusts the time of each trace, bringing all shots and receivers to a common datum, to account for differences in the lengths of the travel paths due to elevation variations. This is critical when dealing with high frequency data such as that needed for this study. For example, with a surface velocity of 500 m/s, an elevation difference of only 0.6 m (2 ft) will result in a difference in two-way travel time of 2.4 milliseconds. If the frequency of the event of interest is 200 Hz, one cycle will be 5 milliseconds long. Thus an error of 2.4 milliseconds will cause a phase error of about a half cycle (180°) causing the data to stack destructively during processing.

A 24-channel field file was selected from line 1 in which part of the geophones were located over intact coal and others were located over the mined void. This field file is displayed in Figure 2 along with a sketch of the geology and approximate raypaths for the nearest and furthest offset traces. The area outlined on the right side of the figure shows reflected waves received over the intact coal seam. A normal moveout (NMO) velocity (see Dobrin 1976 for example) was calculated on this event and was found to be about 500 m/s. An uphole survey was conducted in which a small explosive charge was detonated at the depth of the coal seam and the one-way travel time to the surface was measured. The uphole survey revealed that this reflection was from the coal

Figure 1.

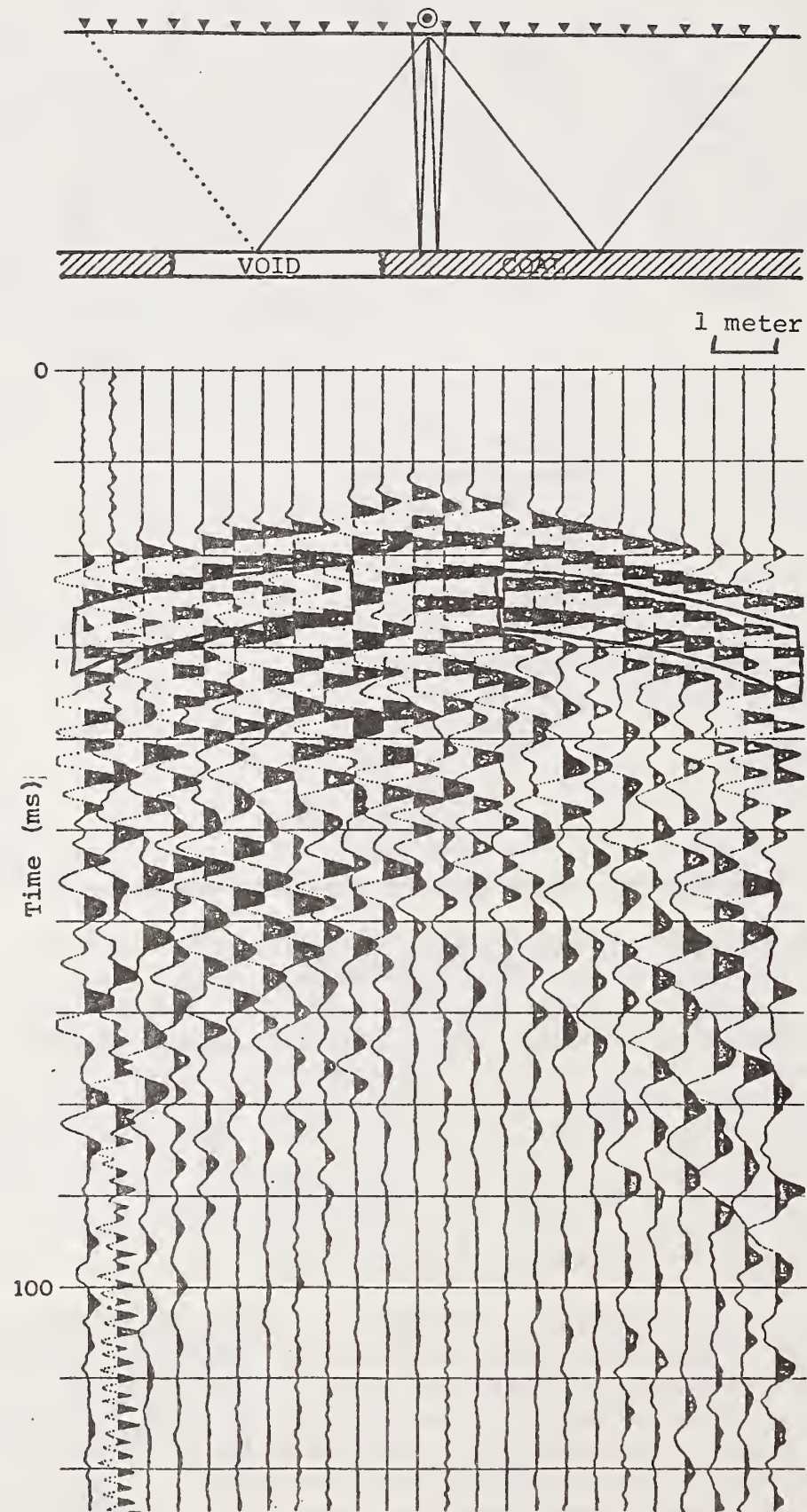


Figure 2.

seam. The area outlined on the left side of the figure represents the signal received over the void and does not show evidence of the reflection.

A 24-channel field file from line 3 is presented in Figure 3. The event outlined on this figure also represents reflected energy from the coal seam.

A 340 Hz, 24 db/octave low-cut filter was applied to the data while recording in an attempt to increase the dominant frequency of the data. A dominant frequency of about 275 Hz was attained, so a 1-m-thick coal seam should be resolvable.

PROCESSING

The data were processed on the Data General MV-8000 computer system at the Kansas Geological Survey, utilizing the Seismic Processing Executive (SPEX) software package by Sytech. The processing steps applied to the data include CDP sorting, trace editing, static correction, MNO correction, CDP stacking, filtering and scaling. In addition, a residual statics process was applied to the stacked data to remove minor undulations in the events of interest which were not totally compensated for with datum statics.

INTERPRETATION

The stacked CDP seismic section of line 1 is displayed in Figure 4 along with an interpreted geological cross-section. Line 1 was shot across two boreholes, one at CDP location 260 which indicates a cavity at 9 m (29 ft) and one at CDP location 346 which indicates intact coal at 9 m. The surface collapse between CDP locations 350 and 405 is approximately 0.7 m deep and is also indicative of a cavity in the subsurface.

The event which occurs at 23-25 m/s throughout most of the section was confirmed by the uphole survey as being a reflection from the top of the coal seam. Areas in which the amplitude of this event diminishes are interpreted as cavities. These areas correlate well with where the drill-hole data and surface collapse indicate cavities in the subsurface. The loss of amplitude of this event over the water-filled cavities is attributable to the contrast of the reflection coefficients. The acoustic velocity of the water in the cavities is greater than the acoustic velocity of the coal, and the overlying shales have an even higher velocity. The reflection coefficient for the boundary between the water and shale will therefore be smaller than the reflection coefficient for the boundary between the coal and the shale, yielding a reduced reflection amplitude over the water-filled cavities.

The event at 28-30 m/s throughout the section is interpreted as a reflection from the bottom of the coal. A velocity pull-up is observed in this event under the water-filled cavities, due to the higher acoustic velocity of the water relative to the coal.

The seismic data for line three were collected approximately one year after the collection of the data for lines 1 and 2. During this time, the Office of Surface Mining had supervised the filling of the mined cavities at this site with a coal ash slurry. These slurry-filled cavities should yield a slightly different seismic character than that observed over the water-filled cavities of lines 1 and 2.

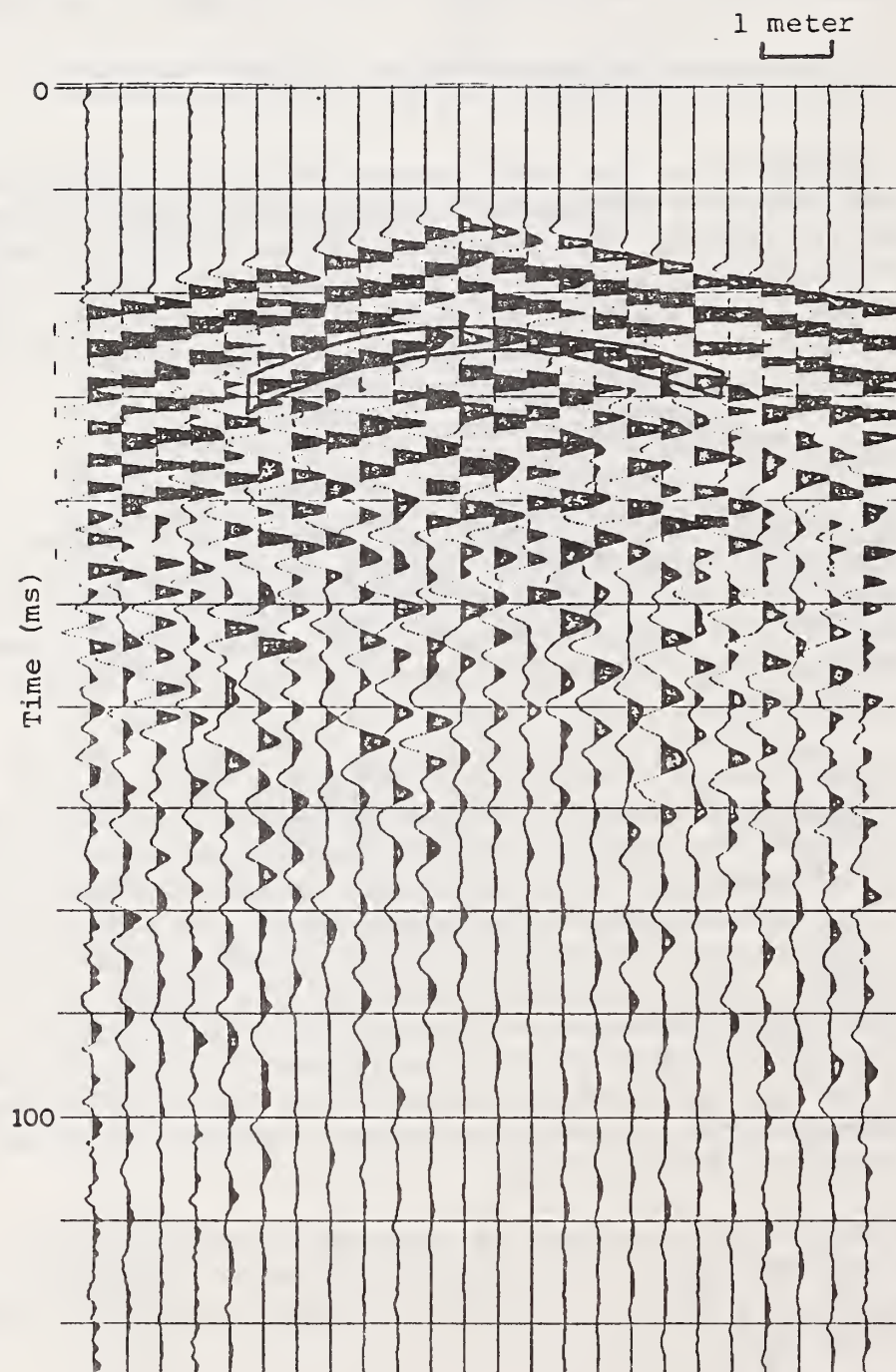


Figure 3.

Line three was shot across two boreholes, one at CDP location 260 which indicates cavity at a depth of 13 m (43 ft), and one at CDP location 394 which indicates coal at a depth of 13 m. The line also traverses a series of fairly evenly spaced, shallow surface depressions, trending east-west and having a maximum relief of about 10 cm (4 in), which suggest a system of cavities in the subsurface.

The stacked CDP seismic section, interpreted geological cross-section, and vertically exaggerated surface topography for line 3 are displayed in Figure 5. The seismic character observed over the slurry-filled cavities is similar to that observed over the water-filled cavities of the previous lines, but less extreme. There is still a reduced amplitude in the reflection event interpreted as the top of the coal over the slurry-filled cavities, but not of the magnitude that was observed over the water-filled cavities. The velocity pull-up of the lower event is more obvious with the slurry-filled cavities. The ash slurry is overall more "coal-like" than the water having a higher density and viscosity, thus the change in the seismic character is more subtle. The locations interpreted as cavity correlate well with the shallow surface depressions and drill data, suggesting that these depressions are probably due to slumping over a system of subsurface cavities.

The region between CDP's 385 and 405 (a distance of only 2 m) on the seismic section is of poor data quality. This is probably due to poor source and receiver coupling, caused by disturbed surface conditions associated with the drilling of the borehole.

CONCLUSIONS

The top and bottom of a 1 m (3 ft) thick coal seam at depths of 9 and 13 m (29 and 43 ft) were resolved. Reflected events from the top of the coal seam exhibited reduced amplitudes over water and slurry-filled cavities. Velocity pull-ups were observed in reflected events from the bottom of the coal seam beneath the water and slurry-filled cavities.

The location of cavities in a 1 m (3 ft) thick coal seam at depths of 9 to 13 m (29 and 43 ft) were located with good resolution. The edges of these cavities were located to within an estimated 1 to 1.5 m (3 to 5 ft) horizontally at this depth.

The high-resolution seismic reflection methods has proven to be very promising for locating abandoned coal mine cavities in southeastern Kansas where the mined coal seam varies from 9 to 13 m (20 to 43 ft) below the surface. Since most surface collapses affecting domestic activity (construction, travel, etc.) occur over mines at these shallow depths, this detection method is a potentially valuable, cost-effective technique for locating these subsurface anomalies.

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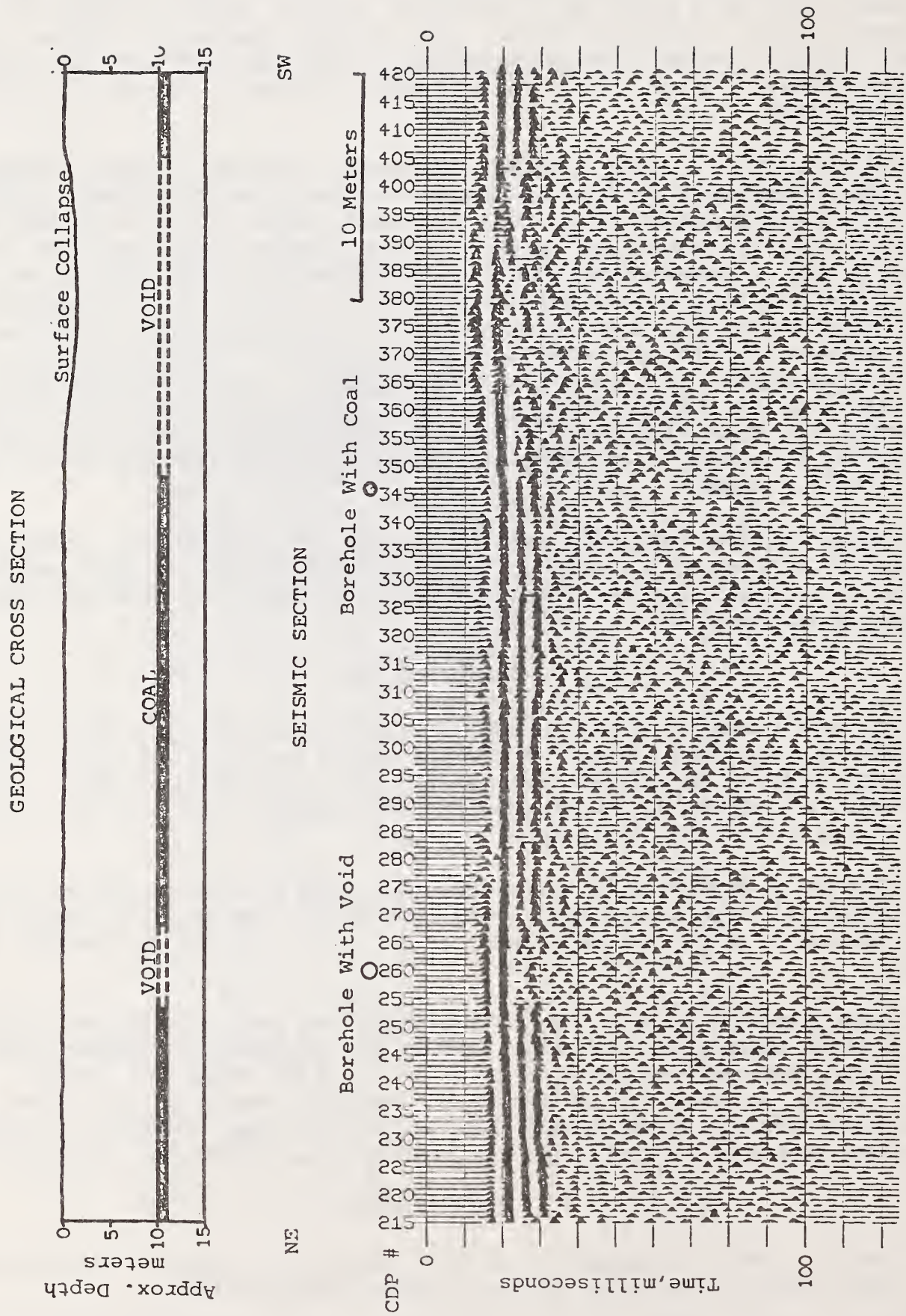


Figure 4.

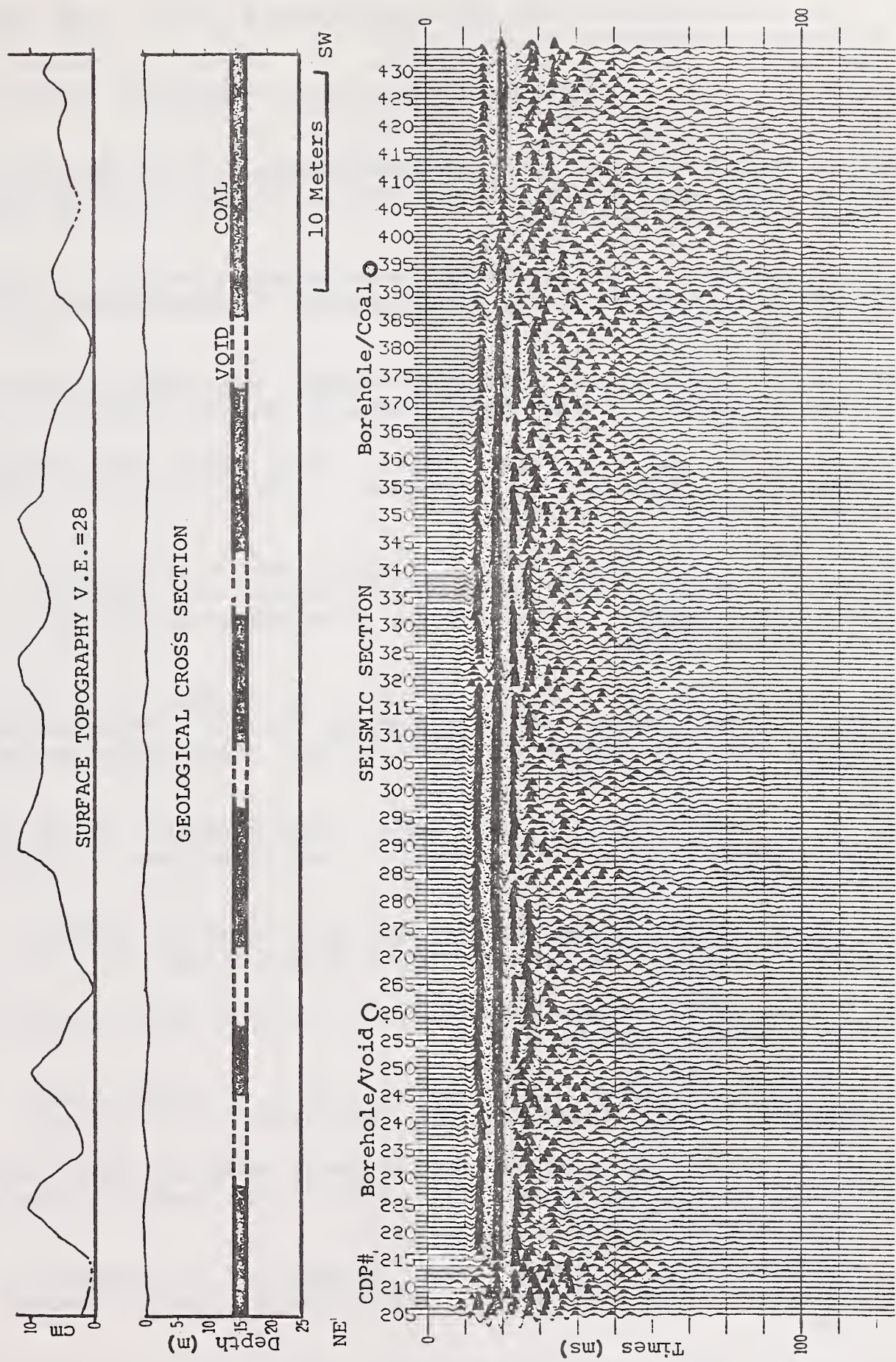


Figure 5.

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CONSTRUCTED WETLANDS FOR TREATMENT OF MINE WATER--SUCSESSES AND FAILURES

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Abstract

Experimental wetlands are being constructed on mined lands in the United States as an inexpensive alternative to conventional acid mine water treatment facilities. Over 30 wetlands constructed in 1984 or 1985 in Pennsylvania, West Virginia, Ohio, and Maryland are currently functioning. In general, it has been found that metals are removed from the mine water by both the wetland vegetation and indigenous bacteria. Adsorption, surface oxidation, ion exchange, bacterial oxidation, filtration, and reduction (in the bottom waters) all contribute; their relative significance varies from site to site and from season to season.

The Bureau of Mines is conducting an inventory of wetlands constructed for acid water treatment as part of a long-term evaluative study. Preliminary results, based on the 20 sites surveyed to date, indicate that the wetlands dominated by emergent species are out-performing the Sphagnum-dominated wetlands. In general, iron concentrations as high as 85 mg/L are reduced to less than 3 mg/L after flow through the constructed wetlands. Manganese is also removed, though somewhat less efficiently. The pH at the discharge, if not above 6, can be raised to that level or higher by flow over limestone.

Maintenance programs appear to be limited to the repair of flow-related damage and occasional additions of fertilizer. Despite limited maintenance, wetland performance appears to increase in the second year after construction as vegetation becomes better established. Long-term observation is obviously still required, but it appears that if inflow water volume is regulated, constructed wetlands can provide effective treatment of acid mine water at a relatively low cost.

INTRODUCTION

Contamination of streams and rivers by acidic mine water is one of the most persistent industrial pollution problems in the United States. The acid lowers the pH of the water, making it corrosive and unable to support many forms of aquatic life. In Appalachia, over 8000 kilometers of streams and rivers are adversely affected by drainage from abandoned coal mines, and this pollution will likely continue unabated for decades (Kim et al. 1982),

Wetlands are a potential natural treatment system for small flows of acid mine water. Two independent studies of Sphagnum moss bogs, undertaken to

determine what adverse effects acid mine water was having on the wetland vegetation, demonstrated a lack of adverse effects and, in fact, natural treatment of the mine water. First, a group from Wright State University studied a site in the Powelson Wildlife area in Ohio where Sphagnum recurveum was found growing in pH 2.5 water. Iron, magnesium, sulfate, calcium, and manganese all decreased while pH increased from 2.5 to 2.6 as the water flowed through the bog. A natural outcrop of limestone located at the downstream end provided sufficient neutralization to raise the effluent pH to 6 and 7 (Huntsman et al. 1978).

A similar study was conducted by a West Virginia University group at Tub Run Bog in northern West Virginia (Wieder et al. 1982). They found that acid drainage flowing into the wetland area rapidly improved in quality. In 20-50 meters, pH rose from 3.05-3.55 to 5.45-6.05, while only 10-20 meters of flow through the bog was needed to reduce sulfate concentrations from 210-275 mg/L to 5-15 mg/L and iron from 26-73 mg/L to less than 2 mg/L. Overall, they found that the water quality of the bog effluent was equal or superior to that of nearby streams unaffected by mine drainage.

The use of natural wetlands for acid mine water treatment is seldom feasible. While examples of long-established natural wetlands receiving acid water from nearby mining operations have been found (Wieder and Lang 1984), it is rare that a natural wetland system is available on a permitted mine area. Also, there are cases where wetland vegetation has been killed as a result of mine water inflow of both treated water (Wieder et al. 1984) and untreated water. The legal barriers to be overcome to use natural wetlands as mine water treatment systems are numerous (Byron 1985), so it would appear that, in general, established wetlands are unlikely to be used for acid water treatment.

FIELD EVALUATION OF TREATMENT BY WETLANDS

The Bureau of Mines is now involved in field evaluation of the wetland approach at mine sites in Ohio, Pennsylvania, Maryland, and West Virginia. Wetlands have generally been constructed by the respective mining companies or state/federal agency (i.e. Soil Conservation Service, TVA, MD BOM, PA DER) specifically for water treatment. The Bureau is facilitating monitoring and evaluation of these sites so that others can learn from these efforts. The Bureau is also cooperating with the National Park Service in constructing a wetland to treat extremely acid water from an abandoned mine at the Friendship Hill National Historic Site in southwestern Pennsylvania.

The constructed wetlands are either Sphagnum-dominant (simulating the previously studied natural bogs) or dominated by emergent species (i.e. Typha and Equisetum). The emergent species were observed to volunteer on mined lands and to also have a beneficial effect on water quality; the earliest full-scale field tests were attempts to enhance this type of volunteer growth. In nine cases, the Sphagnum moss and emergent species have been combined, either by intergrowth or in sequenced wetted areas.

Over 30 such wetlands have already been constructed to treat acid mine water; additional wetlands are being constructed weekly. The Bureau of Mines is conducting a survey of those wetlands that were constructed for acid water treatment prior to 1986. Our intent is to characterize and evaluate wetland construction technology and to provide a data set from which we will select

sites for intensive monitoring. To date, 20 wetlands have been inventoried; they are summarized in Table 1.

Table 1. Summary of 20 wetlands inventoried.

	Mean	Range
Size	929 m ²	93 m ² - 6070 m ²
Number of Sections	3	1- 7
Size of Section	276 m ²	19 m ² - 6070.0 m ²
Flow Rate	0.5 L/s	0.06 - 12.6 L/s
Water Depth	0.4m	0 m - 2 m
Water Chemistry (n = 11)		
Inflow:		
pH	5.8	3.1 - 6.3
acidity	50	ND - 600
Fe	9.6	0.4 - 220
Mn	20	8.7 - 54
Outflow:		
pH	6.5	3.5 - 7.7
acidity	16	ND - 140
Fe	0.5	0.05 - 7.3
Mn	15	0.3 - 52
SO ₄	500	160 - 1500
Construction Cost	\$2750	\$1500 - \$65000

Note: All chemical parameters in mg/L except pH, which is reported in pH units.

In general, constructed wetland treatment systems that have an influent iron concentration less than 30 mg/L and an influent manganese concentration less than 15 mg/L consistently reduce both iron and manganese to less than 2 mg/L. At many sites, much higher iron concentrations are being treated by the wetlands, but only at a few are the iron levels being reduced sufficiently to meet the discharge criteria of 3 mg/L. The highest average iron concentration consistently being treated to that level, at present, is 85 mg/L, though influent concentrations over 100 mg/L are being reduced to 10-20 mg/L.

Manganese removal in these wetlands is inconsistent. One wetland with an average influent concentration of 36 mg/L lowers manganese to 2 mg/L. At another site, manganese is usually reduced from over 70 mg/L to less than 2 mg/L, but performance dropped off during the winter. At still other sites, influent and effluent manganese concentrations are virtually equal. Manganese removal is spatially and temporally variable at some sites while other sites show almost no perturbations. A typical cattail-dominated wetland reduces manganese 20-50%. Sphagnum moss, while very effective in removing iron, is ineffective in removing manganese (Harris et al. 1984; Kleinmann et al. 1985; Wieder and Lang 1986).

Although the planted or transplanted vegetation represents only one aspect of the biological treatment system, failure to thrive is equivalent to failure of the system. Survival of the cattails was evaluated as high in mine water with a

pH of 3 or above, with little replanting necessary and considerable spread during the second growing season. The Sphagnum, in contrast, had lower survival rates; three sites have had to replant the Sphagnum at least once while at other sites, the Sphagnum is only marginally surviving. The Sphagnum is very sensitive to the water level fluctuations that are typical of disturbed lands and some species are also susceptible to "sunburn". It also appears that high levels of iron (greater than 100 mg/L) kill the transplanted moss, possibly due to the high adsorption rate of the moss. On the positive side, Sphagnum tolerates lower pH conditions than the emergent species do, though iron adsorption diminishes rapidly below pH 2.5 (Harris et al. 1984).

The dominant vegetation type determines substrate type. Hay bales or loose hay was used in six of the wetlands in conjunction with Sphagnum, and mixed with clay in another wetland. Spent mushroom compost was included in the substrate layers in three wetlands, while vegetation was planted in spoil or topsoil with clay layers at another three sites. Limestone rock was included as a 15 cm substrate layer in three of the cattail wetlands so far included in the survey. [It should not be considered for use with Sphagnum moss since calcium would be preferentially adsorbed relative to iron (Harris et al. 1984).] Forest duff and manure were also used. Agricultural lime was added after construction on five sites; superphosphate was added in two cases. Reported maintenance included replacing limestone ditch rip-rap, periodic fertilizer application, checking on weir stability, seeding of embankments, grading to limit surface runoff inflow to the wetland, and establishment of hay bale dikes to limit channelization. Maintenance was generally viewed as inexpensive and not time-consuming. One mine site estimated annual maintenance costs as \$20/year; several reported that no maintenance had been done on the wetlands at all.

Several of the respondents commented that they had observed seasonal changes in system performance; in particular, it was noted that pH dropped during the winter months, although metal removal continued. While pH showed a decrease during the winter months in surface water of an Appalachian natural Sphagnum bog (Wieder and Lang 1984), decreases in pH were also found in non-wetland watersheds during the same period. Study by the Bureau of an established cattail wetland which has been receiving acid mine water since August of 1985 did not exhibit lower pH readings of either influent or effluent water during the 1985-1986 winter. Because no mention was made in survey responses of seasonal pH fluctuations of influent water, it is possible that a decrease in pH of water entering the wetland system was simply being passed through in decreased effluent pH. At any rate, the question of seasonal fluctuations in treatment efficiency needs to be investigated over a long-term period of monitoring inflow and outflow wetland water chemistry.

A clear majority of the difficulties encountered with the constructed wetlands were related to water flow and depth control. Bank breaching, regulation of water depth, washout/scouring, and channelization were listed as problems, along with the inability to measure flow rates. We have observed in the past that many of the wetland "failures" to date have been related to high flow damage. The survey results confirm that this is not an isolated problem.

The most frequently mentioned consequence of high flows was the breaching of banks. As most of the wetlands are sited in backfill or spoil material, banks are of only moderately consolidated material. With high water inflow rates and

resulting high water levels, banks tend to give way or to be overtopped and eroded at lower spots. Muskrats and other burrowing animals were implicated in bank damage as well as vegetation damage.

A problem that relates more to the slowing of water as it enters the wetland than to high flow was sedimentation at inflow and outflow structures, more often the latter. This process may be related to the high frequency of pipe outflow structures, as opposed to their frequency of use as inflow structures; pipes, in fact, were most often related to outflow sedimentation problems.

Reported water depths range from 0 to 2 m (0 to 6 ft), with a median of 0.4 m (1.3 ft). As water depth and vegetation type planted in the wetland are related, with cattails and horsetails often planted in water deeper than 0.2 m (0.5 ft), this water depth reflects the preponderance of cattail wetland sections found in this survey. However, it has been observed that treatment efficiency decreases at water depths greater than 0.1 m (4 in). These depths may also point to a causative factor in the observed mortality rate of the Sphagnum moss planted; most species of Sphagnum have difficulty surviving in areas where the water level above the plant is more than 0.02 m (0.07 ft) due to limited diffusion of carbon dioxide (Clymo 1973).

The treatment capacities (excluding freeboard) range from 21.2 to 2470 m³, with three large, deep wetlands skewing the distribution. Detention times range from 0.17 days (4 hours) to 75.4 days, with a median detention time of 4.79 days. In comparison, the detention times in a review of wetlands used for waste water treatment ranged from 2.16 to 145 days (Chan et al. 1982). The wetlands constructed for acid mine drainage treatment thus provide low to moderate detention times. As studies of optimal detention time for metal removal and acid neutralization in these systems have not yet been undertaken, the significance of these detention times is unknown.

Although our survey is limited to sites constructed before 1986, it should be recognized that new wetlands are being constructed on mined lands every week. We anticipate that as many as 100 new wetlands will be constructed this year for acid water treatment. Along with the critical question of optimal loading rates, evaluation of the long-term effectiveness of constructed wetlands in treating mine drainage needs to be addressed. With no constructed systems older than five years, such factors as the relationship between loading rates and treatment efficiency and capacity over time, encroachment of volunteer vegetation, and sedimentation of the systems must all be considered. The Bureau of Mines, in cooperation with Wright State University and with the support of OSMRE will soon initiate intensive long-term monitoring of at least five established wetlands (both cattail and Sphagnum types) currently treating acid mine water. The role of bacteria, algae, plants, and substrate in metal removal will also be examined in the field and laboratory as part of this study.

The Bureau of Mines is also cooperating with the National Park Service to determine if constructed wetlands can be used to improve the water quality of extremely acid water flowing from an abandoned mine at the Friendship Hill National Historic Site in southwestern Pennsylvania. Small scale tests are being conducted at the site to determine which plants can survive in pH 2.6 water that contains approximately 250 mg/L iron and over 1200 mg/L acidity (as CaCO₃). A 0.3 acre wetland will be constructed in August 1986 to accomodate a flow of 4500-9000 L/s (20-40 gpm). If successful, this area will

be expanded to cover 4-5 acres to treat the average site condition of 22500 L/s (100 gpm) and some of the peak flows that range up to 10 times that.

SUMMARY

Constructed wetlands represent an inexpensive alternative to conventional treatment of acid mine water and have therefore gained rapid acceptance amongst mine operators. Preliminary results of an inventory indicates that wetlands dominated by emergent species (especially cattails) outperform Sphagnum-dominated wetlands on mined lands. This may be more related to wetland construction technology than principal planted species since dominant vegetation is only one aspect of the water treatment process. Algae, bacteria, sediment, amendments such as mulch and other plants all contribute to metal removal. Long-term evaluation of the wetlands will elucidate the relative importance of each of these factors so as to optimize water-treatment efficiency.

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MANGANESE REMOVAL FROM MINE DRAINAGE BY ARTIFICIAL WETLAND CONSTRUCTION

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INTRODUCTION

Acid mine drainage (AMD) places a tremendous environmental and economical burden on our nation. AMD has degraded thousands of miles of streams and has rendered countless drinking water supplies impotable at an estimated national treatment cost in excess of one million dollars daily. Conventional AMD treatment is achieved through chemical addition; generally excess alkalinity of chemical oxidants being added to the AMD in a contact/settling pond sequence. Chemical treatment is labor-dependent and under field conditions tends to be an inadequate means of AMD treatment. In many instances, chemical treatment is implemented on a sporadic basis at best; exemplifying the inadequate, short-term nature of this treatment method.

Wetlands are providing us with a much needed alternative to chemical treatment. Current applications utilizing man-made wetlands have proven that wetlands are an effective and potentially long-term solution to the abatement of AMD. Granted, wetland treatment technology has not been "perfected" to the point where every man-made wetland is one hundred percent effective in treating all AMD parameters in all instances. However, wetlands are relatively inexpensive to construct and are not labor-dependent. Once implemented, wetlands become a self-perpetuating and relatively permanent AMD treatment method. In perspective, a wetland treatment system that can continuously improve AMD quality by even 50% on its own merits, is by far a more effective treatment method than a labor-dependent chemical system that may not function at all.

On the other hand, over-treatment (i.e., the addition of chemicals in excess of the amount required to effectively treat AMD) can be even more devastating to the ecology of an aquatic community than the untreated AMD itself. The consequences of over-treatment are particularly ironic under circumstances where mine drainage requires treatment from a legal, rather than a biological standpoint. For instance, a manganese value of five parts per million, in an otherwise totally compliant mine drainage effluent, will trigger the requirements for treatment of the discharge. Careless practices such as over-treatment often ensue, and may lead to a discharge that meets the applicable regulations, but has become a discharge that can disrupt the ecology of the receiving stream to the point where a once viable aquatic community can no longer exist. The technical aspect of the law has been met, but surely not the intent of the law.

A situation such as this at least demonstrates the necessity to further develop wetland technology. In Pennsylvania, particular emphasis is being placed on

the treatment of manganese because of its prevalent occurrence and persistent nature in the region's mine drainage.

BACKGROUND

Abandoned mine lands, an over-abundance of AMD, and the common occurrence of AMD-related volunteer wetlands presented this researcher with an excellent opportunity to study the treatment of manganese in wetlands.

Numerous AMD source and wetland discharge samples were collected from a broad geographical area of western Pennsylvania and analyzed to determine the effectiveness, if any, of the wetlands in treating AMD.

Reductions in iron, sulfate, and acidity, with concurrent increases in pH values were a relatively common finding in the volunteer wetlands, while reductions in manganese levels were relatively rare in comparison. The few effective volunteer wetlands noted, (effective meaning those wetlands that removed a significant portion of manganese from the AMD) were examined in closer detail. While the ubiquitous cattail, Typha latifolia, dominated most of the volunteer wetlands examined, a wealth of aquatic and semi-aquatic plants generally inhabit the typical AMD-generated volunteer wetland in Pennsylvania.

One plant however, the field horsetail (Equisetum arvense), was consistently noted in the "effective" wetlands and absent in the majority of the "ineffective" systems. An examination of the literature did not reveal any AMD/E. arvense related studies, but the coincidental occurrence of E. arvense in the effective wetlands prompted the ashing and analysis of several wetland Equisetum samples. Positive preliminary ashing results of over 4000 mg/kg of manganese on a dry weight basis led to the decision to develop a man-made wetland designed to remove manganese from AMD utilizing E. arvense.

CONSTRUCTION

Through the cooperation of a local coal mining company and the Pennsylvania Department of Environmental Resources, such a wetland was constructed and planted in June of 1985. At this point, an Office of Surface Mining 1985 research grant developed, greatly increasing the opportunity to study the workings of the wetland in detail.

The wetland was designed and subsequently hand-planted as an integrated system. Cattails dominated the plantings, with numerous rush and sedge species strategically located in the wetland. AMD flow was carefully manipulated to maximize surface area and retention time in the wetland. E. arvense was planted down gradient of the main wetland to allow the system to remove the majority of iron from the AMD before the flow reached the Equisetum planting. Since iron is much more readily concentrated in plant tissue than manganese, this design allowed the E. arvense a better opportunity to remove manganese from the AMD. E. arvense was planted in the wetland as mature plants, which did not survive transplant very well, and as rhizomes, which established themselves as above water plants in less than one month. The rhizomes associated with the transplanted mature plants also developed new shoots in the same time period. (It should be noted, that the entire wetland was designed to study the role aquatic vegetation plays in AMD treatment and that nothing

but plants were introduced to the system; e.g., limestone was not used as a base for the wetland to avoid confounding any results).

EQUISETUM

The horsetails are comprised of only one living genus, Equisetum, and are considered to be one of the most primitive of our plants. Equisetum is closely allied to the prehistoric order Calamitales, whose spores produced our large channel coal deposits.

Equisetum is annual in nature above ground and a long-lived perennial below ground. The plant is unique in that the stem, as well as the branches are photosynthetic, although the short-lived fertile stems of E. arvense contain no chlorophyll. Equisetum's rhizomes and roots are very similar to the above ground stems and branches and are widely spreading in nature. The field horsetail, E. arvense, is by far the most common species and is considered a pioneering, weed species by many. E. arvense has an interesting natural history in that it exhibits at least seventeen recognized growth forms, or formae, more than any other plant species. E. arvense will thrive under most any condition, from dry cinders to several inches of water, but prefers damp, semi-shaded habitats.

FINDINGS

Strategic water monitoring points were established in the wetland and sampled on a regular basis, along with periodic ashings and analyses of the wetland vegetation. Following is a brief overview of some early data generated by the described study.

Figures 1 and 2 depict water quality values associated with the AMD point source and the final wetland outflow. Figure 3 shows the relationship between the concentration of iron and manganese in the tissue of E. arvense.

CONCLUSIONS

The data of Figures 1 and 2 show a definite improvement in water quality from AMD source to wetland outflow. Total iron and acidity values are characterized by a significant improvement in quality on a year-round basis at the outflow. Manganese values display an improving trend during 1985, but show little improvement during 1986. The manganese values for the winter of 1986 show an actual increase in manganese from source to outflow; suggesting a possible resolubilization of manganese during this period. Values for pH effluent rose dramatically during the first several months of 1985, but actually decreased to a point below the influent quality during 1986.

Figure 3 shows a definite correlation between iron and manganese concentrations in the tissue of E. arvense.

DISCUSSION

The water quality data of Figures 1 and 2 raises more questions than the data probably answers. It is obvious that the wetland is effective in removing significant amounts of iron on a year-round basis. Mean iron values do increase during the winter months, but remain significantly lower than source

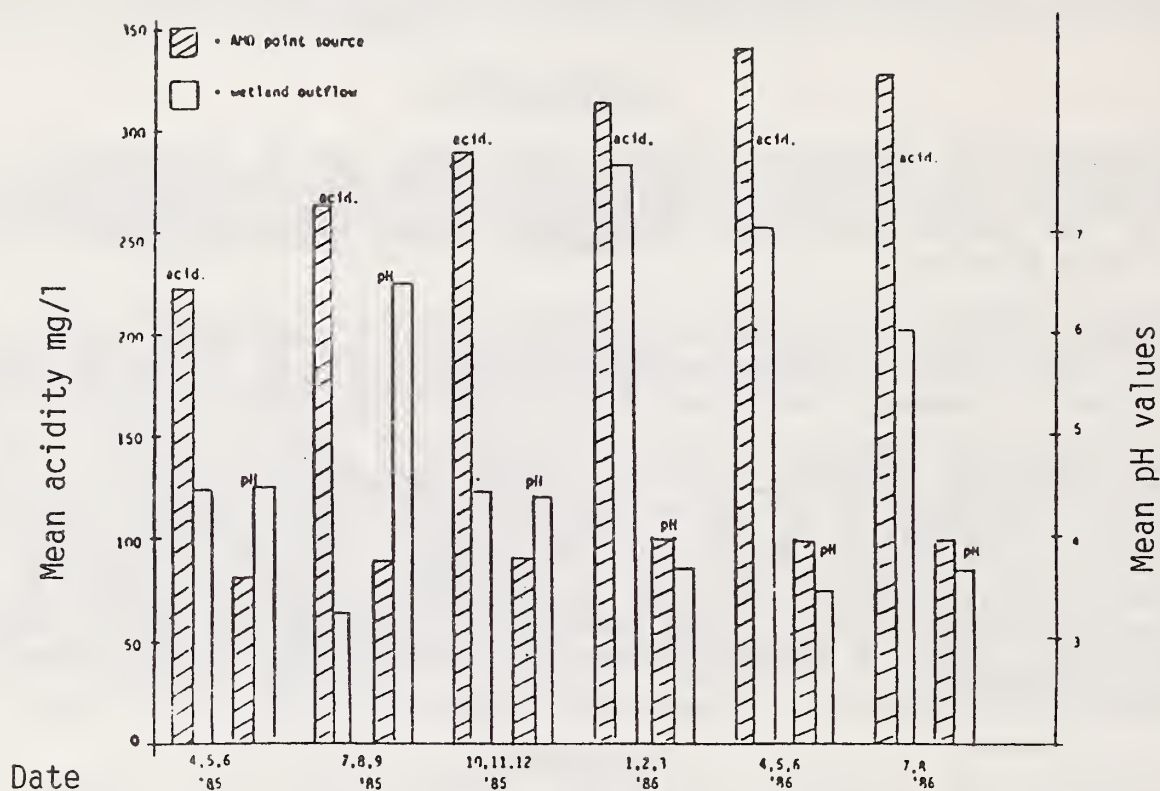


Figure 1. Mean acidity (mg/L) and median pH values.

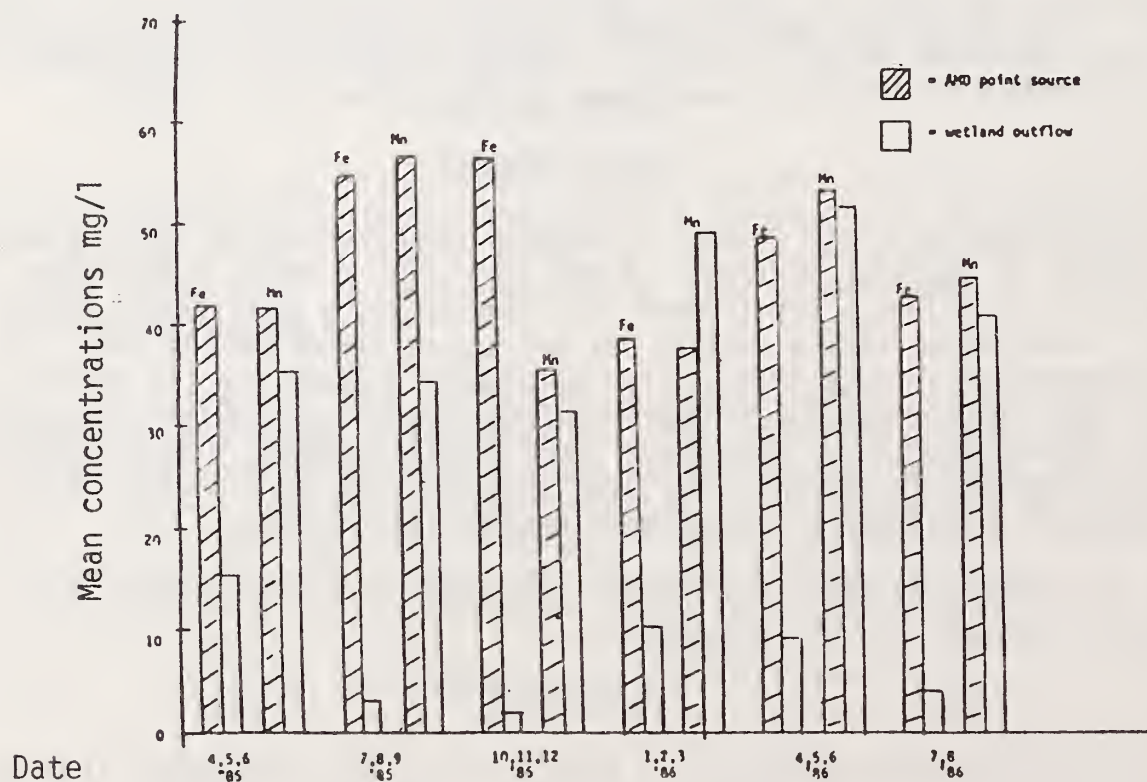


Figure 2. Mean concentration of iron and manganese (mg/L).

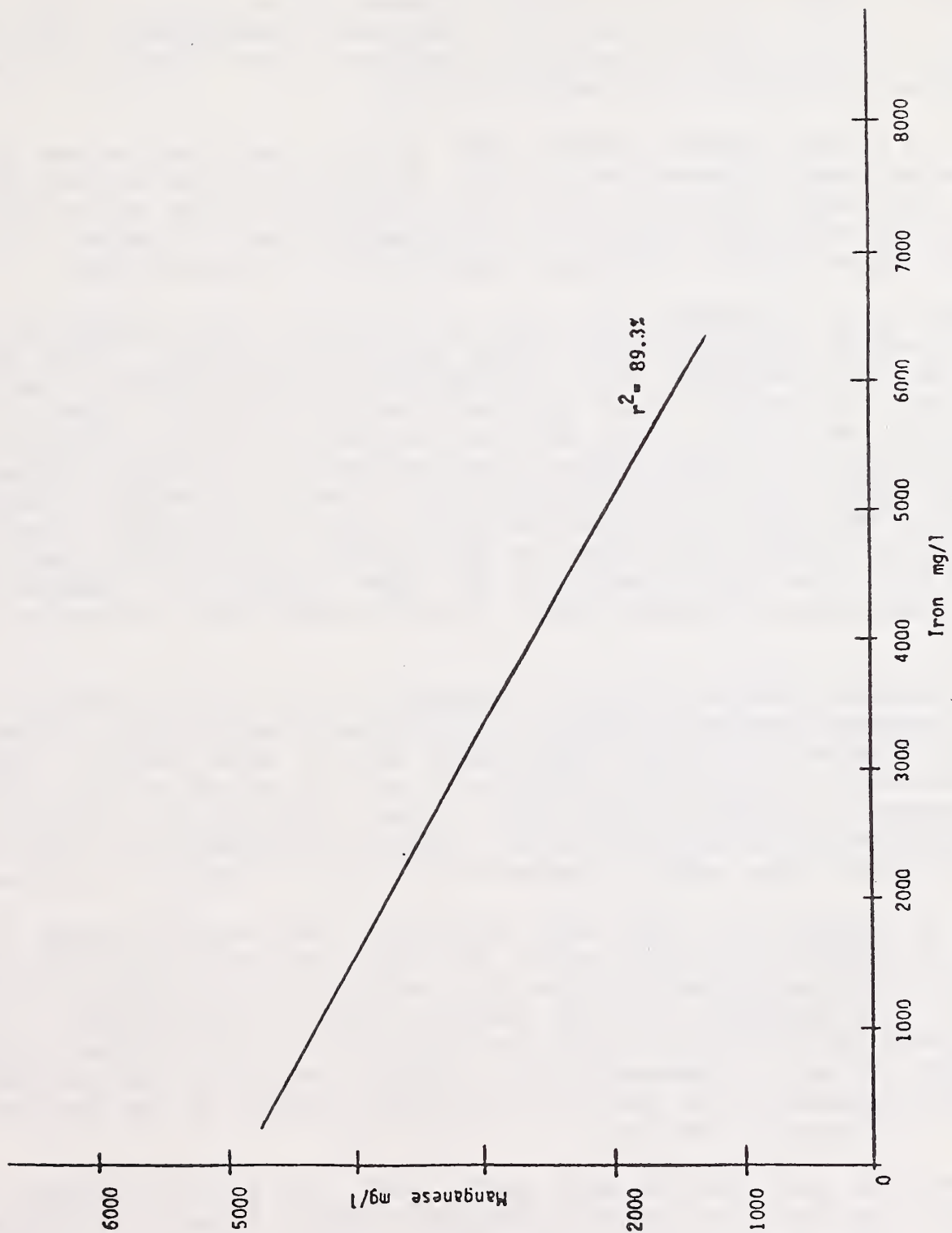


Figure 3. Relationship of iron and manganese in the tissue of Equisetum arvense (values derived from dry weight ashings).

values. Acidity values show a very similar trend to iron as might be expected, although the reductions are not as dramatic as the iron reductions are.

Manganese and pH values also display similar trends in relation to water quality, although they differ greatly from the iron and acidity trends.

The 1985 pH values displayed dramatic increases improving from median values as low as 3.8 to increases of 6.5. Manganese concentrations also showed significant quality improvements during this time period, although neither pH or manganese continued these trends into 1986.

There are several possible reasons why pH and manganese values did not continue to show improvements in 1986. Unfortunately, at the time of this writing the actual reason(s) cannot be ascertained because of the need for further data assimilation during the 1986 growing season. However, the most probable causes of these unexpected trends will be discussed briefly.

Excessive rains, displaying pH values as low as 3.0 have plagued the 1986 research efforts throughout the spring and summer months. This growing season has been extremely "wet", confounding the interpretation of any data taken from the wetland. The rains have definitely played a direct role in keeping pH values low in the wetland, but may also have suppressed the values indirectly by keeping algae in the wetland from blooming. Research is presently being conducted to determine if the increased pH values of 1985 were at least partially due to blooms of blue-green algae in the wetland. Along with the rain, the second year growth in the wetland has effectively taken over most of the open water areas that the algae inhabited the season before further reducing any beneficial effects the blue-greens may have had on water quality.

The relationship between positive pH adjustments and algae populations in AMD wetland treatment systems requires a concentrated research effort to determine the role of algae on a seasonal and diurnal basis in these systems. There is also evidence to suggest that blue-greens are responsible for concentrating large amounts of manganese from AMD. Current work by the author, including ashing results in excess of 50,000 mg/kg of manganese on a dry weight basis in wetland algae samples, emphasize the need for research in this area.

As for E. arvense, the early data assimilated from wetland ashings is also positive concerning manganese removal from AMD. Figure 3 depicts an expected inverse relationship between iron and manganese. The more iron concentrated in the Equisetum, the less manganese that is concentrated. (These same results have also been shown for algae and to a lesser extent, Typha). Therefore, it may be assumed the E. arvense would be most effective at removing manganese from AMD if no iron was present in the flow when it reached the Equisetum planting.

This trend was also shown in water quality data. The less iron available to E. arvense in the flows, the lower the manganese effluent values at the Equisetum planting. Therefore, it appears essential to design wetlands to remove iron from the AMD before a concentrated effort is made to remove manganese.

In summary, the early data shows a positive ability for wetland vegetation to remove manganese from AMD. Wetland design is critical in determining the

effectiveness of the wetland in manganese removal, as is the selection of vegetation. Further findings of this study should determine the loading rates of E. arvense in concentrating manganese as well as the plant's survivability and turn-over rate. It is hoped that this work will aid in the design and implementation of wetland treatment systems that will effectively treat AMD and provide an alternative to chemical treatment.

ECOLOGICAL, DESIGN AND REGULATORY CONSIDERATIONS FOR WETLANDS TREATMENT OF MINE DRAINAGE FROM THE PENNSYLVANIA MINE

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INTRODUCTION

A passive mine drainage treatment system has been designed and constructed in Colorado at the Pennsylvania Mine which discharges severely degraded water quality into Peru Creek, a tributary feeding Dillon Reservoir (Denver's water supply). This system employs a natural wetlands to remove heavy metals from the mine drainage. Design and construction of the treatment system has raised a number of interesting and difficult technical and policy issues. For example, use of wetlands for mine drainage treatment could imply a trade-off between possible degradation of the values associated with the wetlands in return for improved surface water quality. Assessing the magnitude of this trade-off requires detailed ecological investigations which must be carried out over the long term (for prototype systems).

Difficult design problems are encountered when trying to handle mine water at an elevation of 11,000 feet with poor access conditions, severe winter weather and a lack of electrical power availability. Finally, this system has raised numerous questions about the appropriate regulatory framework to accommodate such approaches to mine drainage treatment. This treatment approach encroaches upon traditional regulatory jurisdictions of the Clean Water Act "404 Dredge and Fill" permit program and the "NPDES" water quality permit system. Special use permit requirements from the Forest Service have also come into play.

Finally, EPA is proposing to develop regulations for mine waste (including mine drainage) under the Resource Conservation and Recovery Act. Attempts by public and private entities to abate mine drainage impacts using passive approaches may result in the assumption of unlimited liability for such hazardous waste as defined under RCRA. What may be viewed as a mine drainage treatment system from one perspective may be viewed as a hazardous waste disposal facility from another perspective.

PERU CREEK AND THE PENNSYLVANIA MINE

Peru Creek drains the west slope of the Continental Divide, where Gray Peak and Torrey Peak form one summit of Colorado's Blue River drainage. The elevation of the Peru Creek watershed lies above timberline in the alpine tundra zone. The Pennsylvania Mine is located at 11,000 elevation in the Peru Creek

drainage. There are numerous avalanche chutes in the vicinity of the mine adit. The area is accessible by a four-wheel-drive road from mid-June to November. During the winter, however, access is possible only by snowmobile or cross-country skiing.

Acid mine drainage from the abandoned Pennsylvania Mine continually discharges into Peru Creek. The range of flow from the Pennsylvania Mine has been measured over the past five years in the range of 45 to 170 gallons per minute. This drainage causes a severe water quality impact upon Peru Creek. The instream metals concentrations in Peru Creek become severely elevated, after the mine water has mixed with the receiving stream. Cadmium, copper, lead, and zinc are elevated well above the maximum allowable concentrations for cold water aquatic life.

MINING HISTORY

Silver was first discovered in 1864 near the Pennsylvania Mine site. By 1870 a silver rush established underground mining in this area which peaked in the 1880's. There has not been significant production from the Pennsylvania Mine since the early 1920's. However, an estimated 50 miles of tunnels exist at the mine as the result of mining operations. Ground water flows into these drifts and tunnels and discharges at the abandoned mine adit.

The metal deposits sought by miners were mainly a mixture of copper, lead, zinc, silver and gold. This mineral complex was commonly associated with pyrite. The pyrite, in combination with air and water, oxidizes to produce acid which, in turn, dissolves the metals in the ore bodies that were developed by miners.

PREVIOUS INVESTIGATIONS

The Colorado Division of Wildlife (1974) and Trout Unlimited have done water quality testing and surveys of aquatic life in Peru Creek. No populations of aquatic species are able to survive in the degraded water quality of Peru Creek below the Pennsylvania Mine. The U.S. Forest Service performed a water testing program in 1977. In 1978, the Colorado Water Quality Control Division and the Forest Service carried out a comprehensive water quality inventory of mining impacts in the Peru Creek Watershed. All point sources of mine drainage were identified and evaluated.

THE PENNSYLVANIA MINE DRAINAGE TREATMENT SYSTEM

The results of the point source evaluation in Peru Creek revealed that the primary and major source of mine drainage is the Pennsylvania Mine. Over 50% of the metals observed in the stream are attributable to this one mine. Therefore, it was considered worthwhile to address this one source, despite the fact that many other mines discharge in the watershed. Water quality modeling indicates that if the contamination from the Pennsylvania Mine is eliminated, conditions supporting aquatic life may be restored.

A cooperative effort with the Northwest Colorado Council of Governments and the Colorado Mined Land Reclamation Division resulted in the design and construction of a wetlands treatment system for this discharge. A number of alternatives were considered before arriving at the wetlands approach. Lack

of power and winter access precluded construction of a conventional physical/chemical treatment system. The feasibility of constructing an artificial wetlands was evaluated. However, the quantities of mine water to be treated would have required a sizable lowland or flatland building site for the artificial bog.. The only area fitting that description was already occupied by a mountain sedge wetland. The existing meadow was selected to provide treatment for the mine drainage.

Prior to operating the system, the concerns of the Army Corps of Engineers 404 permitting agency, the Colorado Department of Health NPDES permitting agency, the EPA NPDES permitting authority and the U.S. Forest Service have been addressed in the construction of the system and the monitoring program developed for it.

ECOLOGICAL CONSIDERATIONS FOR WETLANDS TREATMENT OF MINE DRAINAGE

The design for monitoring wetland vegetation adjacent to Peru Creek was developed by researchers at the Colorado School of Mines and the Thorne Ecological Institute. The experimental design includes the analysis of vegetation composition, production and phenology within the wetland. The wetlands assessment also addresses the analysis of plants and soils for metal accumulation, and the diversity and relative abundance of invertebrates in the wetlands.

The design utilizes a single wetland that includes an experimental and two control plots. Actually, there are numerous vegetation quadrants within these major study areas. The experimental plot will receive acid mine drainage, while the control areas will not. An assumption is that the extra amount of water received by the experimental wetland will not be a significant uncontrolled factor during the investigation. A goal of the vegetation monitoring is to determine which species are accumulating what metals, in what concentrations, and in what parts of the plants are the metals being stored. Soils are being analyzed to determine the rate of metal accumulation in the soils. These analyses relate the responses of different plant species to the input of metals.

Invertebrate species emerging from the wetlands will be captured in traps placed along transects in homogenous patches of vegetation. The invertebrate composition and abundance study will determine how the composition and abundance of the invertebrates present in the wetlands change over time.

Ultimately, a metal cycling model will be developed that utilizes acid and metal data input from the mine water, acid and metals retained in the soils and plants, and metals in the water output from the wetlands. This model will allow a quantitative analysis of the wetland performance in removing acids in metals, and the response of various species to the acids in metal accumulation. Expected results from this project will create a large body of data on wetland plant species, wetland vegetation, and wetland soils. The entire wetland will be assessed as a functioning system.

HYDROLOGIC MONITORING OF THE WETLANDS TREATMENT SYSTEM

Surface water flow measurements are made bi-weekly at the Pennsylvania Mine adit, the manhole at the head of the mine water leach lines and the six established stream monitoring stations along Peru Creek. Ground water level

measurements are made at a total of 14 wells installed in the experimental and control areas within the wetlands. The piezometric surface and hydrologic gradient of the water table will be determined from the ground water elevations. The entire project area was surveyed using a total station with location and elevation control provided by a USBLM monument. Aquifer characteristics such as transmissivity and permeability will be determined for the ground water in the wetlands.

WATER QUALITY

Surface water quality samples are taken bi-weekly in conjunction with the flow measurements. Samples are collected at the Pennsylvania Mine adit, the man-hole at the head of the mine water leach lines, and at the established stream monitoring stations along Peru Creek. Water quality parameters analyzed in the laboratory include total recoverable phosphates, aluminum, iron, manganese, copper, zinc, nickel, molybdenum, cadmium, chromium, barium, and lead. Salts evaluated in the laboratory include calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate, nitrate, chloride, and boron. Field measurements of pH, conductivity, and temperature are made at the time of sampling. Ground water samples are collected from the 14 monitoring wells described above. The same water quality parameters are analyzed for ground water as for surface water.

AQUATIC BIOTA MONITORING

Personnel from the Colorado Division of Wildlife and EPA are assessing the presence or absence of aquatic biota in Peru Creek with the goal of establishing the minimum conditions necessary to support aquatic life in the stream. Personnel from EPA have assessed and conducted initial monitoring of benthic populations in the wetlands. No individuals have been collected thus far in the live traps.

SYSTEM PERFORMANCE

Operational features of the mine drainage collection, conveyance, and leach field systems will be assessed on an ongoing basis. The effects of winter temperatures and spring runoff will be monitored closely. Particular attention will be paid to flow distribution in the perforated leach lines and any precipitate build-up in the water handling systems.

DESIGN CONSIDERATIONS FOR THE WETLANDS MINE DRAINAGE TREATMENT

The goal of any passive mine drainage treatment (PMDT) system is to focus "bio-geochemical" water treatment mechanisms at or near the source of mine drainage, in order to accelerate the pollution removal that would otherwise occur naturally, but over a much longer reach of the receiving stream. Artificial bogs and wetlands are the cornerstone of PMDT. The sizing requirements for bogs and artificial wetlands are based on laboratory and field observations for cation exchange capacities and transmissivity characteristics of peat and wetlands environments. A number of wetlands treatment systems have been designed and constructed in the recent past. Hopefully, in the near future, actual operational data will supply the needed hydrological information for designing systems. The wetlands area available for treating the Pennsylvania Mine drainage far exceeds the amount determined necessary from

laboratory tests and previous field demonstration projects. The cation exchange capacity in the meadow is sufficient to provide adsorption of metals for at least 90 years, even assuming no other metal removal functions are operating in the bog or fen, in this particular case.

The plant species which are dominant in natural wetlands are often adapted to the acid conditions and elevated heavy metal and salt concentrations which are associated with acid mine drainage. Wetland plant species and the organic peat substrate in bog areas remove metals from acid water by adsorption or cation exchange. The wetlands also remove metals by plant uptake. Some wetland species are able to concentrate high levels of metals above ambient conditions. In fact, the sedges in the wetlands adjacent to Peru Creek show elevated concentrations of metals which, apparently, were adsorbed and uptaken from naturally mineralized runoff waters. In addition, iron and sulfur reducing bacteria are no doubt important in removing or demobilizing metals from mine drainage.

The Pennsylvania Mine PMDT is located in an extreme environment. The entire system was placed underground to avoid freezing problems in the harsh winter season. The conveyance system was buried beneath an avalanche chute in order to drop the mine drainage 80 feet vertically from the mine adit to the wetlands. Thrust blocks were provided at each bend in the pipe to minimize hydraulic ram effects on the pipeline. A subsurface energy dissipator tank receives water from the conveyance pipeline and delivers the drainage under pressure to the wetland. The buried exfiltration (mine water leach field) system was insulated with outdoor polystyrene to prevent freezing and ice damming. The mine water is allowed to leach out along a wetting front 500 feet across the wetland.

Since the water level is the major factor influencing the development of the wetland, it is beneficial to install water handling devices which can aid in the control of inflow and outflow from the bog system. A bypass system to route water around the wetlands is also desirable.

The natural wetland treatment system at the Pennsylvania Mine will not be operational until late this summer. The system was constructed in late fall, 1985, but the onset of winter prevented completion of the series of ground water monitoring wells. This will permit any changes in the wetlands to be related to water quality. Also the plants in the wetlands will be monitored as mentioned earlier. Given the large area of the wetlands in a small discharge of mine water (approximately one gallon per minute for 5,600 ft² of wetlands), it is likely that a high metal removal efficiency will be observed at this site.

The design cost for the Pennsylvania Mine wetlands treatment system amounted to \$10,500. Construction costs were \$24,400. This system is a prototype. Construction was hampered by the onset of winter in the fall construction season. Costs were higher than expected because of the need to accelerate construction to complete the project before winter arrived. The monitoring costs are of major significance. Over the long term, these costs will dwarf the design and construction costs.

REGULATORY CONSIDERATIONS

Construction of PMDT systems requires careful consideration of applicable permit requirements. In the eastern coal regions, regulatory agencies often require that chemical treatment be available if needed to supplement wetland treatment, since this approach is considered experimental. NPDES discharge permits are routinely required for systems constructed at active coal mines in the East. In Colorado, NPDES discharge permits have not been required for the existing demonstration treatment systems. These systems were allowed to be constructed as demonstration projects at inactive mines, in order to evaluate the feasibility of the PMDT approach.

Section 404 (PL 92-500) Dredge and Fill permits may also be required for construction work in bottomlands, in order to enhance or develop wetlands for mine drainage treatment. A 404 permit was not required for the particular work done at the Pennsylvania Mine. This is because the actual construction work took place outside of the wetlands. An effort is currently underway in Colorado to propose an appropriate comprehensive regulatory framework for future PMDT applications involving natural and artificial wetlands.

It should be noted that EPA policies on mining wastes under RECRA and CERCLA are in a period of transition. The transition involves moving from an individual program, single resource perspective, to an integrated regulatory program for mining wastes. EPA has proposed regulation of mining waste under Subtitle D of RECRA. Also, EPA has concluded, and the courts have agreed, the CERCLA pertains to mining waste due to the presence of "hazardous substances" in these wastes.

The view of mining wastes (including mine drainage) as hazardous waste under RECRA and CERCLA may severely constrain states' abilities to address these problem areas using the wetlands approach. It is likely that states may be considered potentially responsible parties under CERCLA, if they become involved in manipulating these wastes using low cost and low maintenance techniques to abate impacts. While wetlands environments offer tremendous metal removal capacity, they are very leaky vessels from a hazardous waste containment point of view.

The wetlands approach offers a means of retaining metals near the point of release from a mine. The wetlands is not a perfect containment system. The release of mine water from the bog is slower and more spread out into the receiving stream than a direct discharge from a mine. The natural assimilative capacity of the receiving stream is maximized by routing the mine water through a bog. The bog spreads the overwhelming impact of mine drainage direct to a stream, to tributary ground water and wetlands ecosystems prior to discharging to the surface drainage system. Natural processes and resources are incorporated in the treatment system. The impact is better balanced but spread to other resources. Use of artificial and natural wetlands may be an ecologic approach to mine drainage abatement, but it appears to be headed on a collision course with new directions in mine waste regulation and containment.

MAN-MADE WETLANDS FOR ACID MINE DRAINAGE CONTROL

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Abstract

A series of shallow impoundments planted with a variety of wetlands emergents was constructed in May 1985 to treat acidic (red water) drainage emanating from the toe of a fine coal refuse impoundment dike at the Tennessee Valley Authority's Fabius Coal Preparation Plant in northeastern Alabama. Flora and fauna within the wetlands (both transplants and invaders) showed rapid growth and expansion. Comparisons between the seeps and final effluent showed substantial reductions in manganese, iron, and solids during July 1985 through June 1986 and increases in pH and dissolved oxygen. In December an additional 75-150 l/m of pH 3.5 water discharged into the wetlands reduced treatment efficiency, but the system gradually recovered after the acidic flow was terminated.

INTRODUCTION

Red water drainage, primarily from coal mining and processing, lowers water quality, impacts aquatic biota, and jeopardizes drinking water supplies throughout the Appalachian coal fields, as well as western mining areas and throughout the world. In 1978 EPA estimated that 11,000 miles of rivers and streams in Appalachia were negatively impacted by acid drainage.

Conventional treatment technology primarily consists of grading and recontouring to reduce or divert flows and the addition of alkaline solutions to elevate pH levels and chemically precipitate metallic ions. Land reforming is almost prohibitively expensive, and chemical treatment is not only expensive but often requires a long-term maintenance and operational commitment. Man-made wetlands appear to offer an inexpensive, self-maintaining, long-term solution that may be applicable to small or large flow acid discharges.

Several investigations have suggested or demonstrated the effectiveness of wetlands in removing acidity, sulfate, iron, manganese, and other pollutants from acid mine drainage (Huntsman et al. 1985; Weider and Lang 1982; Weider et al. 1984; Guertin et al. 1985; Holm 1983; Huntsman et al. 1978; Pesavento 1985; Holm 1985; Brodie 1985). Some have described failures of demonstration wetlands to achieve desired results (Pesavento 1985; Weider et al. 1985).

Laboratory studies have explored design and operational parameters of wetlands for acid mine drainage treatment (Burris et al. 1984; Gerber et al. 1985; Kleinmann 1985; Tarleton et al. 1984; Brodie et al. 1985). Most existing

experimental or operational wetlands have adapted or simulated peat bogs with Sphagnum, Polytrichum or Hypnum mosses as the dominant vegetative species. Although generally successful in removing iron, manganese, and some other metals from acid mine drainage, peat bogs are naturally acidic within values commonly between 3.2 and 4.0 (Clymo 1984). Thus, a moss-dominated treatment system may not be able to achieve effluent limitations for pH. Consequently, some researchers have incorporated limestone neutralization into wetlands systems (Harris et al. 1984; Kleinmann et al. 1983; Guertin et al. 1985; Holm 1984; Kleinmann 1985).

However, natural marsh type wetlands, dominated by emergent plant species (Typha, Scirpus, Eleocharis, Juncus) frequently occur at acid water seeps emanating from a variety of natural and man-caused sources. Our field investigations suggest that many of these system provide considerable water quality improvement. In addition, marsh type wetlands have been used for municipal wastewater treatment for many years, resulting in design guides and publications which have application to designing and operating treatment wetlands for acid mine drainage (EPA 1985; Hammer and Kadlec 1983; Nichols 1983; Hyde et al. 1982; Tchabanoglous 1980; EPA 1979; Brezonik et al. 1981; Zoltek 1979; Spangler 1976). Preliminary design guidelines for constructing wetlands to treat acid mine drainage have also been suggested (Brooks 1984; Pesavento 1984; Kleinmann et al. 1985).

Little work has been done on pollutant removal mechanisms of wetlands for mine drainage treatment. Physical/chemical mechanisms may include ion exchange on substrate surfaces, precipitation and sedimentation, coagulation, chemical filtration, volatilization, absorption, chelation, and sulfate reduction (Chan 1982; Hammer and Kadlec 1983; Herricks 1982).

Vegetative and microbiological mechanisms are thought to be important, if not the major factors in pollutant removal. These may include cation exchange on plant surfaces, physical filtration, uptake of pollutants through plant/substrate and plant/water interface and translocation of pollutants through plant vascular systems, uptake and immobilization of pollutants in plant litter zones, microbiological oxidation of iron and manganese, and sulfate reduction (Carruccio 1984; Gregory 1982; Stone 1984; Chan 1982; Clymo 1984; Oborn 1962; Olem and Unz 1976; Emerson et al. 1982; Herricks 1982).

Results of various systems have been multidirectional, and more importantly, few systems have been studied over long time periods (op cit). Intuitively, we suspect these systems will provide self-maintaining water treatment for extended time periods since similar natural wetlands appear to have accomplished these functions over geological times.

SITE DESCRIPTION

Since November 1971 two coal refuse (coal slurry) disposal ponds have existed on the 104 ha site of the Tennessee Valley Authority's (TVA) Fabius Coal Preparation Facility in Jackson County, Alabama (Figure 1). In 1979, the facility was mothballed. In 1984 TVA decommissioned the facility and began reclamation. Reclamation was to include mitigating seepage at the toe of the dike of Slurry Lake 2.

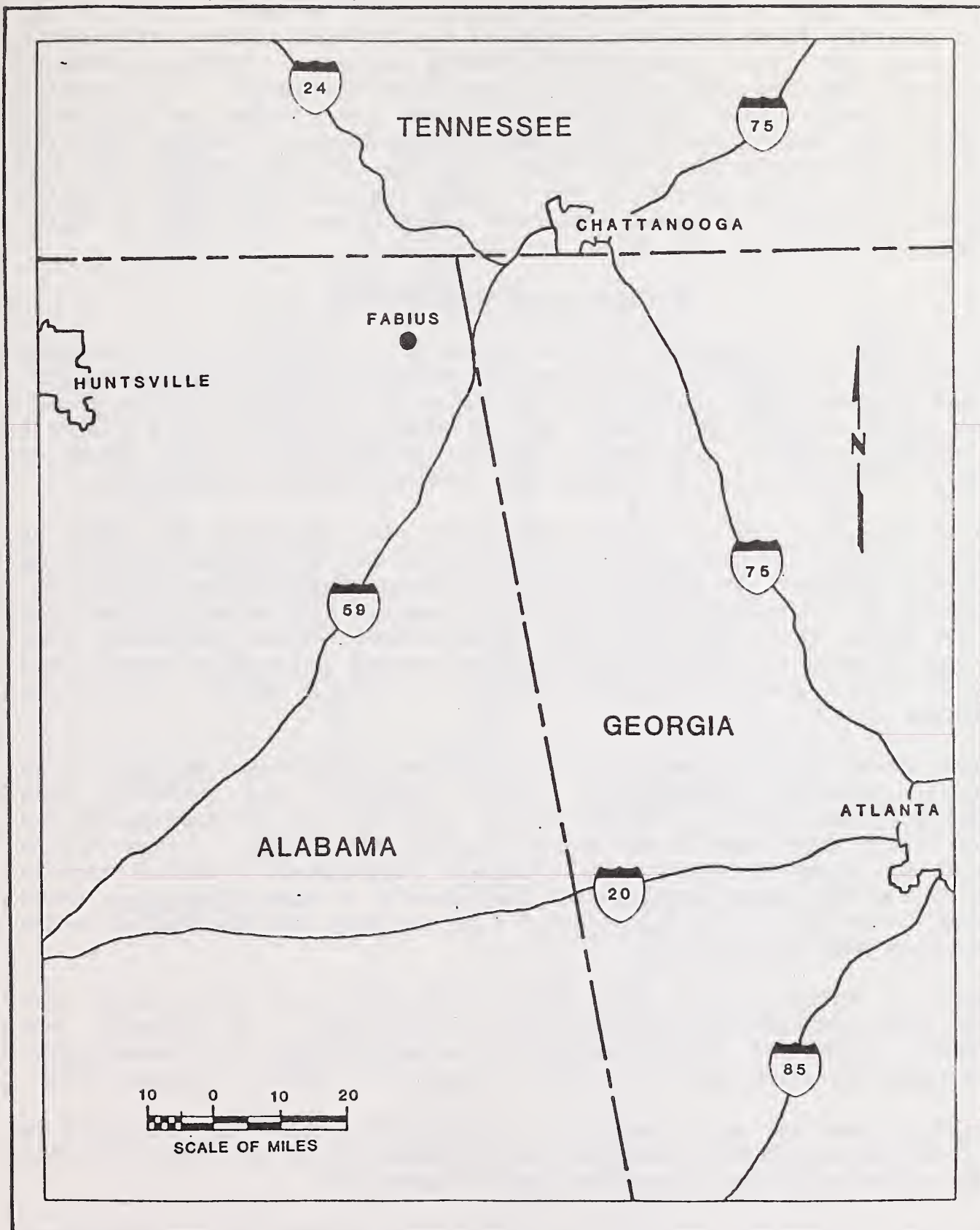


Figure 1. Location of TVA Fabius coal preparation plant.

In 1979, the slurry lakes consisted of 17 ha of fine (minus 28 mesh) coal refuse and water impounded by a 585-meter-long earthen dam (Figure 2). The total drainage area at the primary spillway for Slurry Lake 2 was 147 ha. Runoff generally flows over the surface of exposed coal slurry and becomes highly acidic (pH = 3.5), necessitating chemical treatment. During operations, slurry water was decanted and either treated and discharged or recirculated for process water. After operations ceased, the slurry water was pumped to the Fresh Water Lake where it was treated and discharged. Seepage along the toe of the dike was identified in 1976 and subsequently monitored for flow and quality. Flows ranged from 30 to 106 l/m with total iron averaging 80 mg/L, manganese exceeded 10 mg/L, dissolved oxygen was less than 2 mg/L, suspended solids exceeded 98 mg/L, and pH was 6.0.

METHODS AND MATERIALS

In April 1985, a marsh/pond wetland system was selected to treat seepage emanating from the toe of the coal slurry impoundment dam. Existing topography was established and specifications developed to create the maximum practical amount of shallow water wetland and to delineate boundaries of a small (10 m²) existing wetland. Bulldozers cleared approximately three acres of woodlands and constructed four dikes with overflow spillways (Figure 3).

Hand clearing and felling trees perpendicular to anticipated flow patterns preserved most of the existing wetland vegetation and reduced flow channeling or short-circuiting. In addition, seven sandbag dikes created smaller impoundments in the immediate vicinity of the seepage and below the discharge pipe for acidic water from the slurry impoundment. Total impounded water area approximated 0.6 ha. Plants were deliberately selected at nearby acid seeps to obtain plant populations adapted to similar edaphic and aquatic conditions.

In early June, laborers hand-dug and transplanted bulrush (Scirpus), rush (Juncus), spikerush (Eleocharis), cattail (Typha), and scouring rush (Equisetum) from natural stands at nearby seeps into the sandbag ponds and shallow water (less than 7 cm) areas of the larger ponds. Larger plants (Typha) and clump-forming species (Scirpus) were spaced at one/m² whereas those with smaller habits were planted five-ten/m². A moss (Philonotes) found growing in association with Equisetum at a nearby seep was also planted within the sandbag pond at Seep 1.

Scirpus and Juncus clumps were thrown into the wetland from ashore and Typha were individually pressed into the substrate. To stimulate new vegetative growth and to prevent wind throw some plants were broken over. Triple super phosphate was broadcast at a rate of 505 kg/ha in August 1985.

Since donor locations were nearby and transplanting sites were inundated by impounded water, planting materials were transported in the bed of pick-up trucks without additional precautions against dehydration.

Weekly water sampling was initiated on July 2, 1985, and included samples from two primary seeps, four locations within the system, and the final discharge point. Parameters analyzed by the TVA Laboratory Branch using standard methodologies (EPA 1979) included pH, Eh, dissolved oxygen, Al, Ca, Cu, total Fe, dissolved Fe, Mg, total Mn, dissolved Mn, Zn, and total suspended

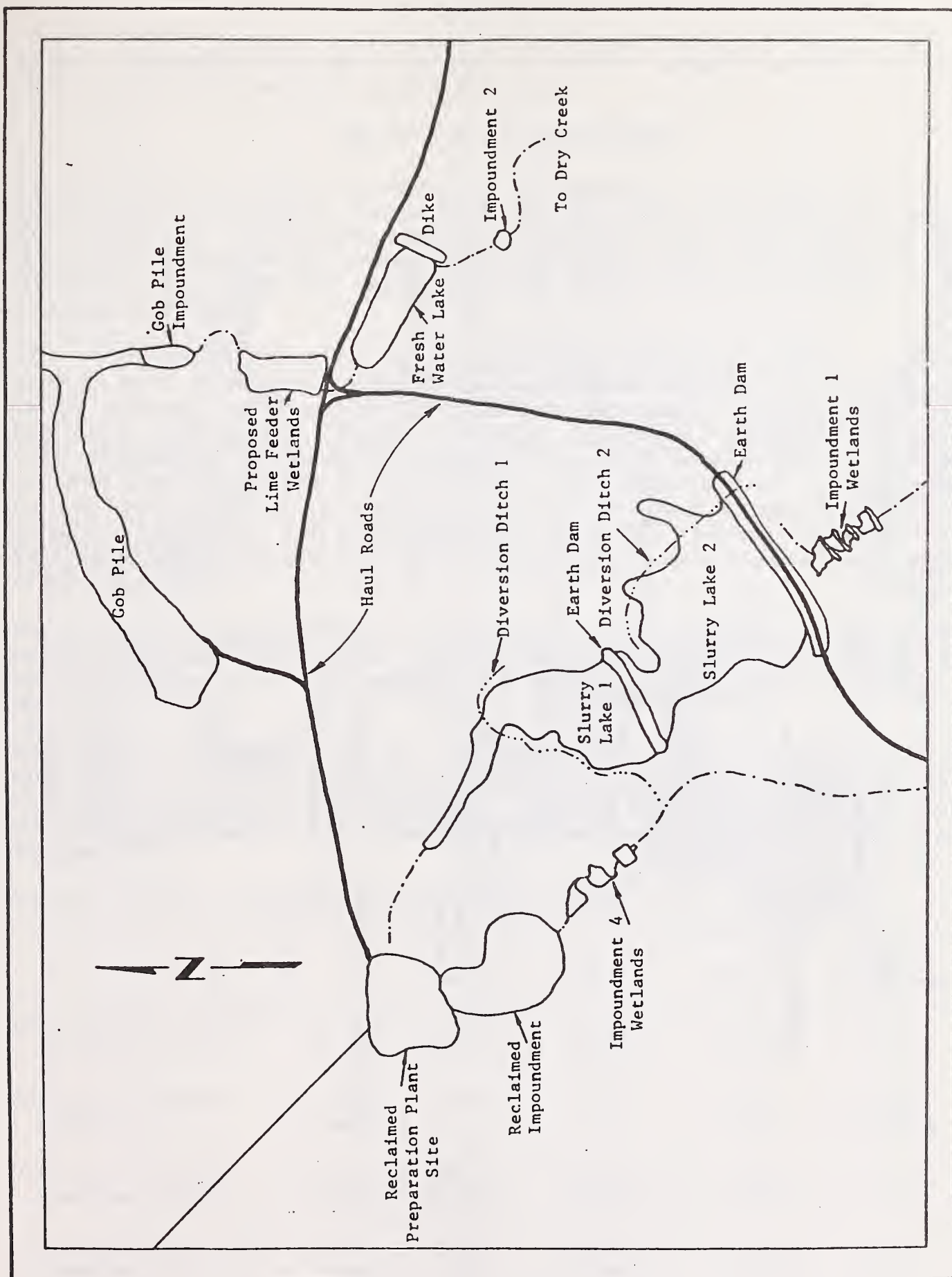


Figure 2. Fabius preparation plant, Jackson County, Alabama.

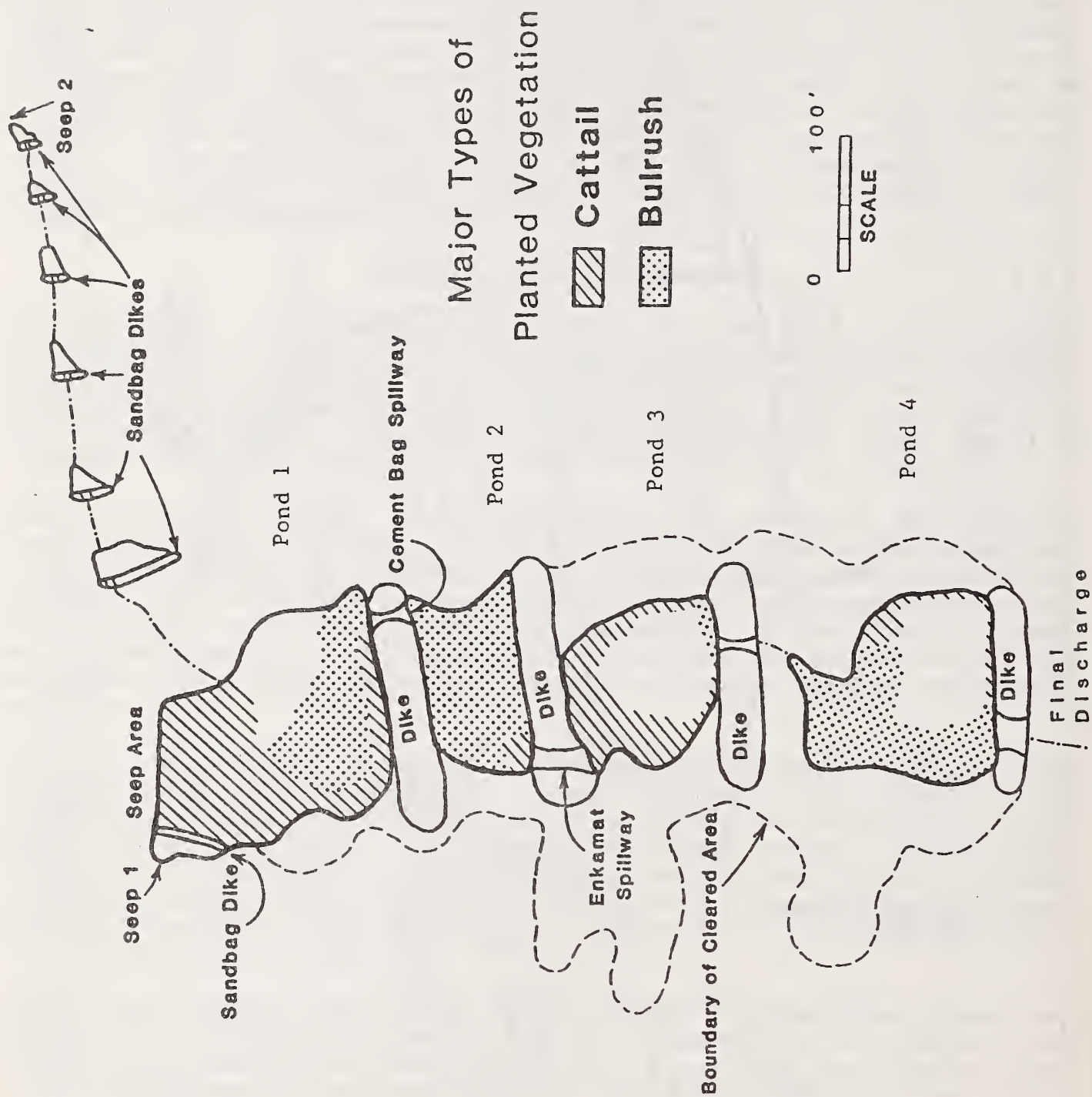


Figure 3. Slurry Lake 2 wetland treatment system.

solids. Monitoring was later reduced to biweekly samples for pH, Eh, DO, total Fe, total Mn, and total suspended solids.

RESULTS AND DISCUSSIONS

After clearing and dike construction was completed, we were surprised to discover five small and two larger seeps emerge within the marsh/pond system. Most apparently had discharged directly into the small stream resulting from the two previously known seeps at the toe of the dike. Unfortunately, one large and one small seep were located in Pond 3 and two smaller seeps occurred in Pond 4.

With the possible exception of the Equisetum/Philonotes complex, vigorous growth and considerable vegetative reproduction occurred in transplanted cattail, rushes, and bulrushes. In addition, Utricularia, Potamogeton, Carex, Sagittaria, Echinodorus, Cyperus, Bidens, Polygonum, Leersia, and Alisma were accidentally introduced or naturally invaded. Density transect sampling revealed that Typha had become dominant over much of Pond 1, Typha and Scirpus were dominant in Ponds 2 and 3, and Pond 4 was dominated by Scirpus, Eleocharis, and Echinodorus by July 30. Limited success of the Equisetum/Philonotes plantings was believed caused by excessive water depth at planting sites.

Mosquitofish (Gambusia affinis) and fathead minnows (Pimephales) were stocked in the ponds and within a few weeks considerable Gambusia reproduction was evident. Frogs and toads responded naturally as did numerous species of invertebrates.

Water quality monitoring showed significant improvement within three weeks after completion of the wetlands system. At the final discharge, dissolved oxygen increased to nearly 6.0 mg/L, total Fe declined to 0.7 mg/L, total manganese averaged 1.0, and total suspended solids averaged 3.0 (Table 1 and Figures 4-7).

Table 1. Range and average water quality values.

		Seep 1	Seep 2	Pond 1	Final Discharge
pH (standard units)	Avg.	6.0	5.9	5.7	6.1
Baseline: 6.3	Range	5.7-6.4	5.6-6.5	4.5-7.0	5.1-7.2
Dissolved Oxygen (mg/L)	Avg.	0.2	3.0	5.91	7.82
	Range			0-10.7	5.3-13.8
Total Iron (mg/L)	Avg.	79.8	82.4	3.6	1.1
Baseline: 30.0	Range	24-140	57-103	0.6-20.5	0.4-6.8
Total Manganese (mg/L)	Avg.	7.74	11.51	5.1	2.8
Baseline: 9.1	Range	4-9	9.3-12.0	0.7-16.2	0.2-17.0
Total Suspended Solids (mg/L)	Avg.	85	103	6.5	2.8
Baseline: 57	Range	33-140	54-260	1-19	1-9

FINAL DISCHARGE QUALITY

July 1985 through June 1986

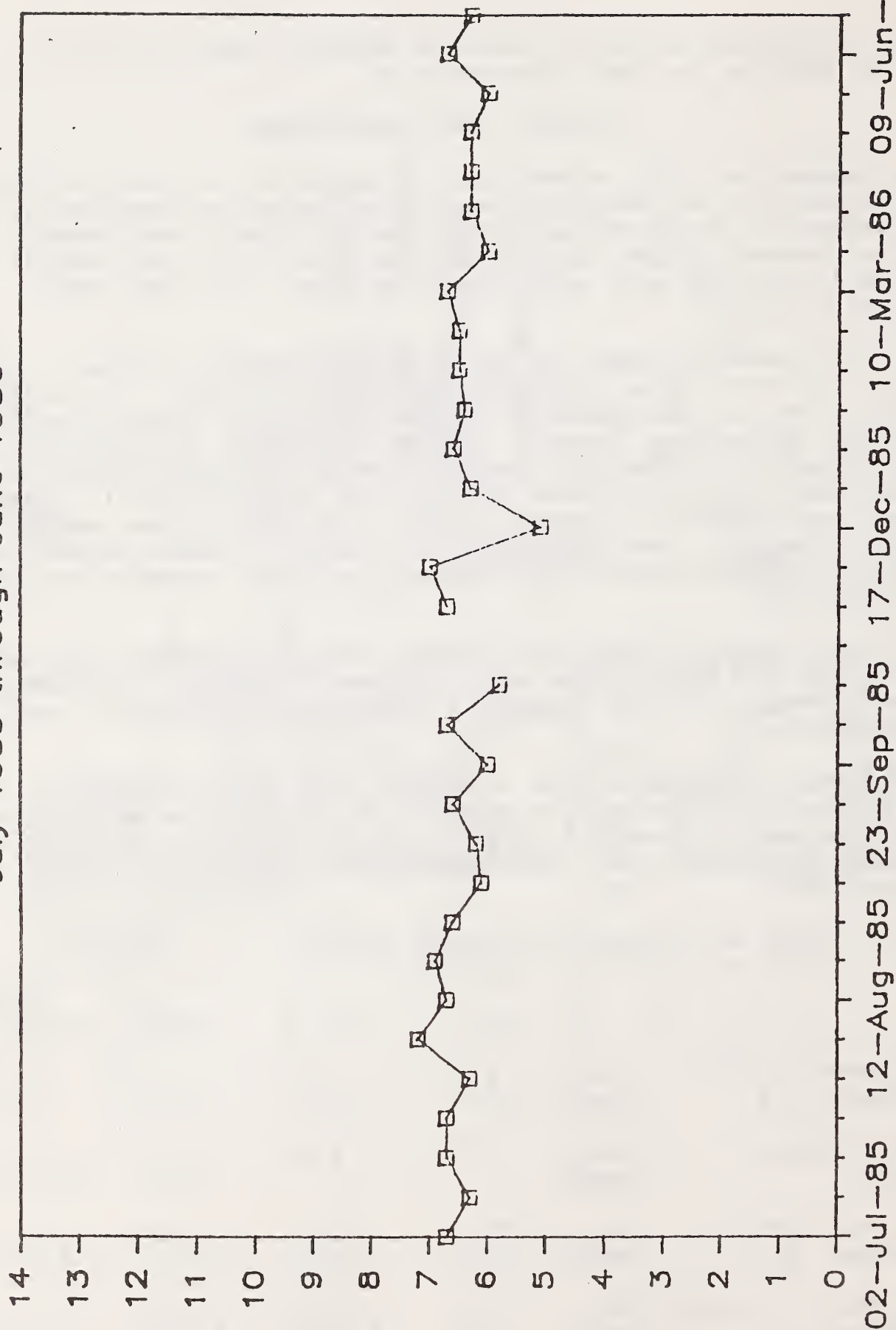


Figure 4. Levels of pH at discharge monitoring station, Fabius site.

FINAL DISCHARGE QUALITY

July 1985 through June 1986

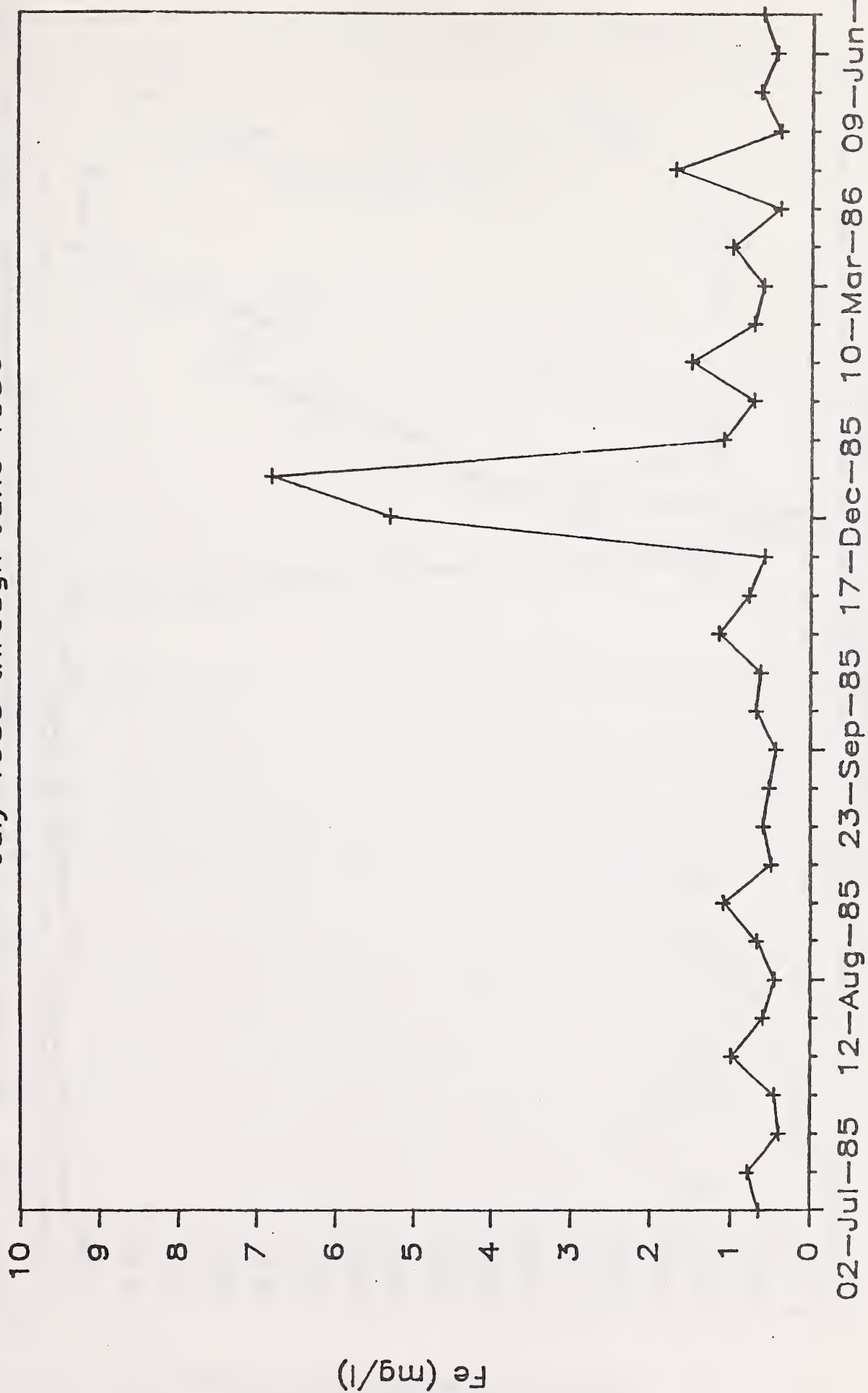


Figure 5. Iron levels at discharge monitoring station, Fabius site.

FINAL DISCHARGE QUALITY

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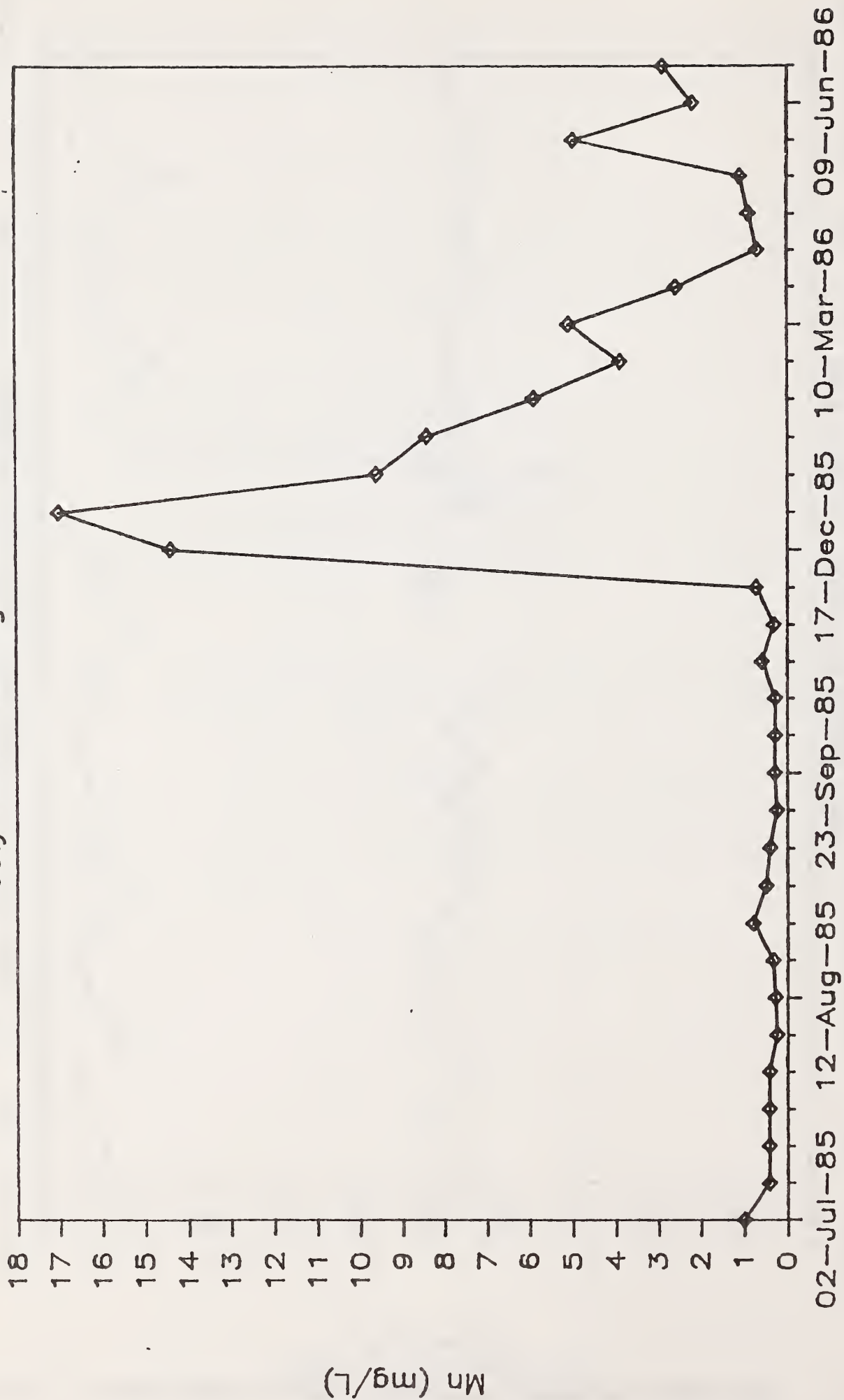


Figure 6. Manganese levels at discharge monitoring station, Fabius site.

FINAL DISCHARGE QUALITY

July 1985 through June 1986

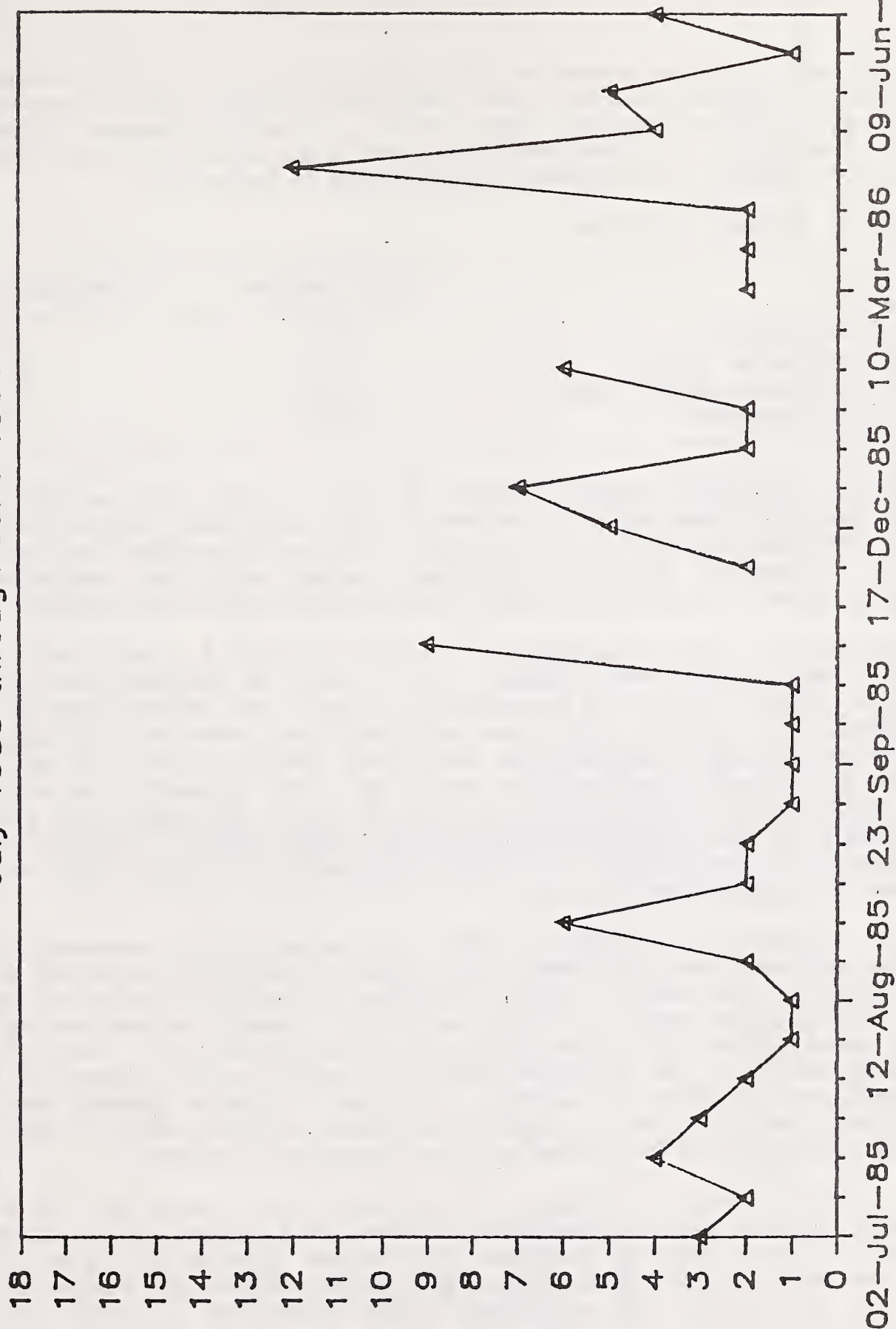


Figure 7. Total suspended solids at discharge monitoring station, Fabius site.

Comparison of sample parameters from the outlet of Pond 1 with baseline seep parameters demonstrated that most contaminant removal from water from the original two seeps occurred within Pond 1. However, because of additional seeps downstream, the final discharge would have exceeded effluent limitations (Table 2) without the additional treatment area in Ponds 2-4.

Table 2. Effluent limitations.

Parameter	Daily Maximum	Monthly Average
Total Iron (mg/L)	6.0	3.0
Total Manganese (mg/L)	4.0	2.0
Total Suspended Solids (mg/L)	70.0	35.0
pH (standard units)	6.0-9.0	-

Although fluctuating slightly, values for pH, Fe, Mn, DO, and TSS in the final discharge were equal to or better than comparable values from undisturbed natural streams on the Cumberland Plateau throughout the summer and fall. In addition, the iron precipitate coating rocks was redissolved and aquatic insects and small fish became reestablished within the receiving stream.

On December 3, 1985, discharges of 75-150 l/m of pH 3.5 water from the coal slurry impoundment were initiated. By the end of December, the final discharge pH fell below 6, Mn increased to 17 mg/L, and Fe increased to 7 mg/L (Figures 4-7), and the slurry lake discharge was terminated. Final effluent Fe concentrations (7 mg/L) were lower than baseline values (80 mg/L) suggesting continued Fe removal was occurring. The substantial increase in Mn (17 mg/L) over baseline levels (8 and 12 mg/L) suggested that previously deposited Mn was undergoing dissolution by acidic inflow. Comparative inflow and outflow values before and after introduction of slurry lake water are shown in Figures 8 and 9.

After cessation of the additional inflow, pH values quickly recovered, total Fe in the discharge was less than 2 mg/L within a month, but Mn levels remained elevated until late March. Despite shocking the wetlands system by inputting a relatively large quantity of highly acidic water during the nongrowing season (ice covered the ponds from January 14 to February 3), the marsh/pond system recovered the functional ability to modify acidic seepage to natural stream water quality. In addition, vigorous vegetative growth and normal vertebrate and invertebrate populations evident in April indicated that macrobiotic components of the system were not permanently damaged.

On May 21 we began releasing 1.9 l/m of slurry lake water into the wetlands system and on June 18 increased the flow to 3.7 l/m. Water quality has remained within effluent limitations and we are hopeful that gradual introduction of slurry lake water during the growing season will permit adaptation by the microscopic and macroscopic biotic components to lower pH levels. Successful treatment of the slurry lake decantation will eliminate the need for pumping and chemical treatment.

Total costs for construction of the marsh/pond wetlands system approximated \$28,000. Comparable chemical treatment is estimated to cost \$10,000 per year for acid seep water not including initial construction of a treatment basin or

AVERAGE INFLOW & OUTFLOW

FOR 4 SIGNIFICANT PARAMETERS

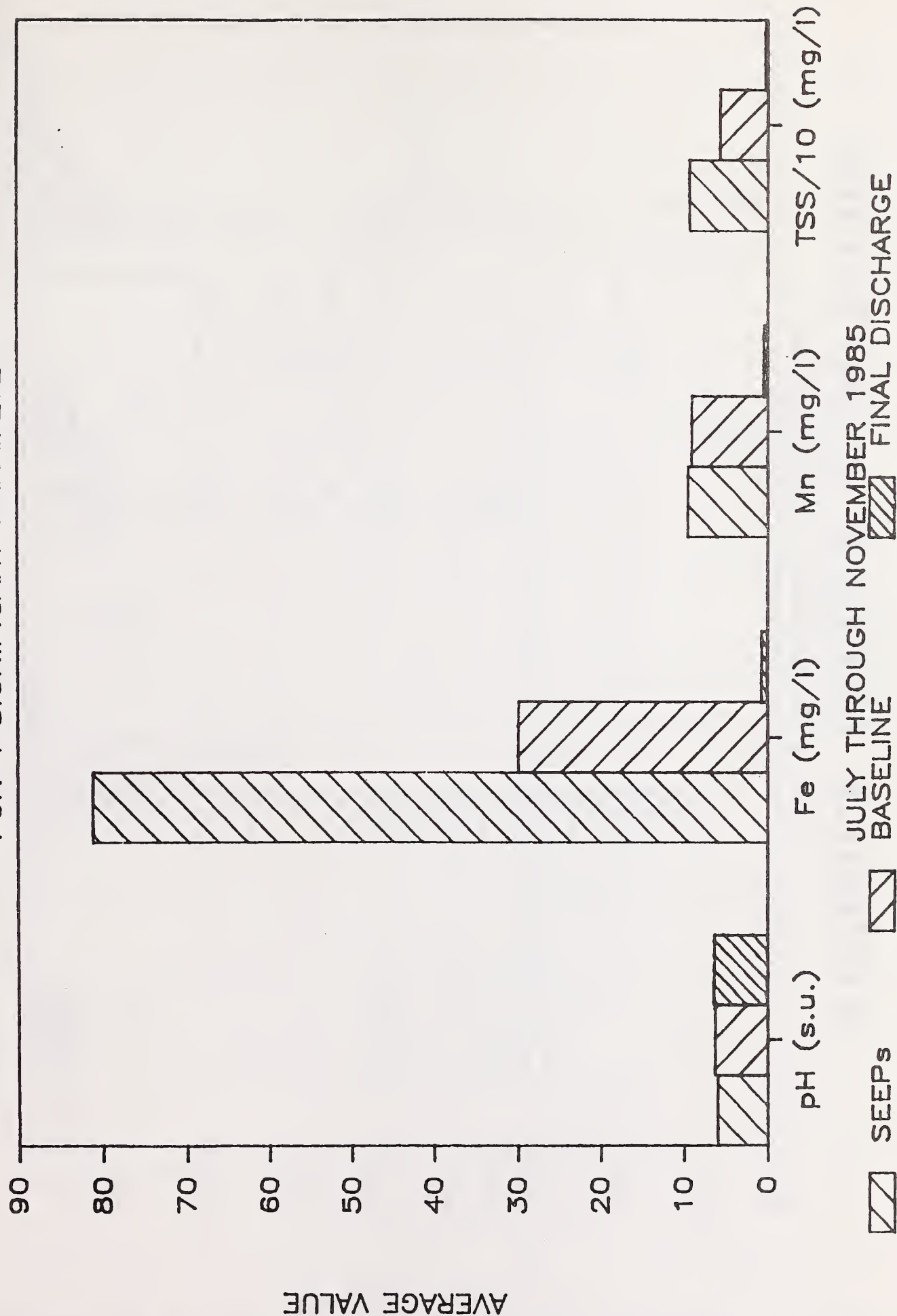


Figure 8. Inflow and outflow values for pH, Fe, Mn, and TSS before addition of Slurry Lake 2 low pH water.

AVERAGE INFLOW & OUTFLOW

FOR 4 SIGNIFICANT PARAMETERS

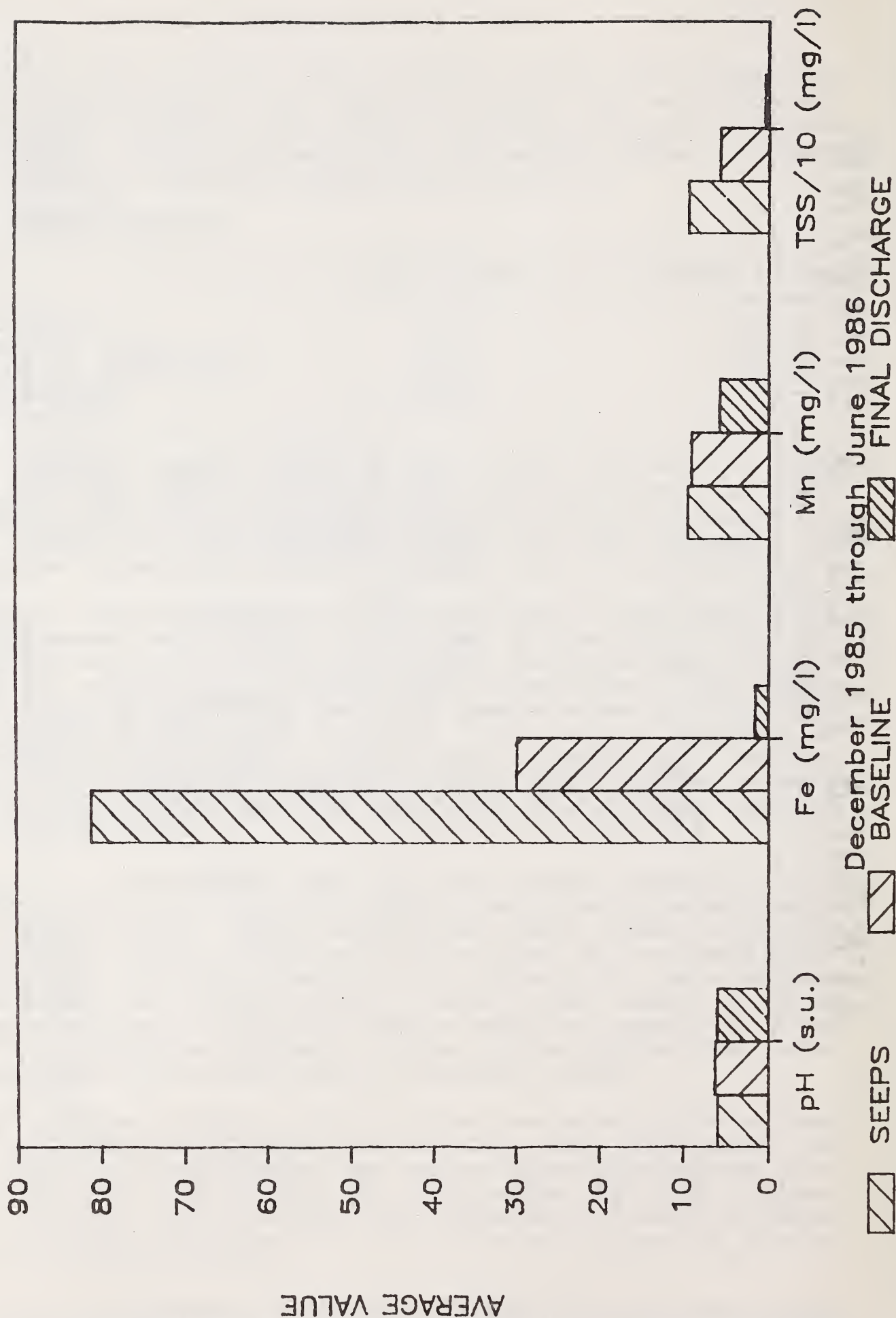


Figure 9. Inflow and outflow values for pH, Fe, Mn and TSS after addition of Slurry Lake low pH water.

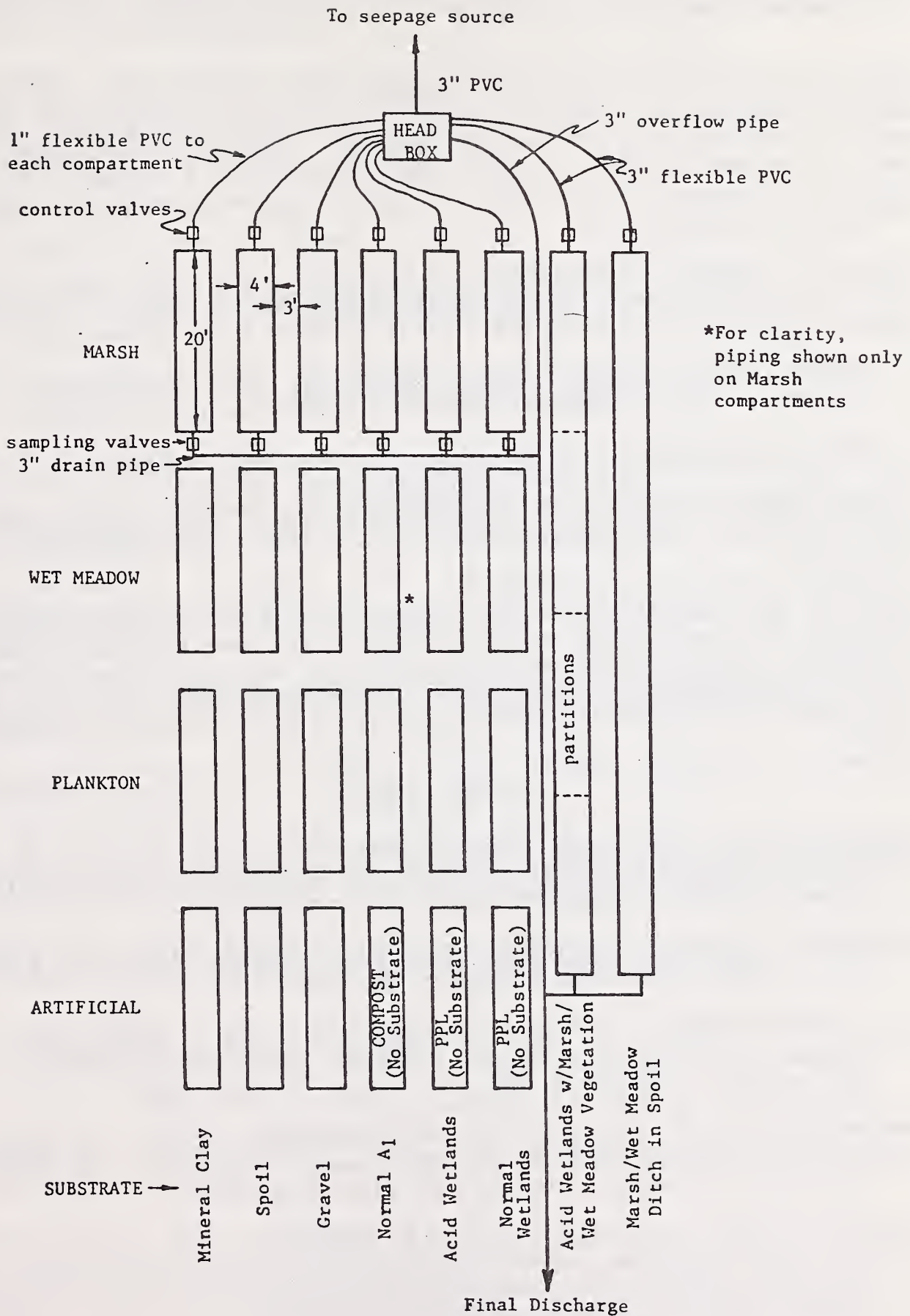


Figure 10. Schematic of research wetlands.

treating the slurry lake discharge. If the wetlands system continues to provide adequate treatment, it will have proven cost-effective.

However, the competitive advantage of man-made wetlands over chemical treatment is based not only upon the immediate, short-term economics but upon the internal maintenance attributes of wetlands systems that suggest long-term independent functioning of stabilized systems. Reasonable assurance or relatively long-term treatment of acid water discharge by a wetlands system will overcome reluctance of regulatory agencies to approve additional applications and permit terminations.

Although a thorough understanding of the biotic factors and treatment mechanisms is probably years and substantial dollars in the future, two immediate questions for which the entire coal-related industry needs answers are:

1. What are the design criteria regarding size, configuration, depth, substrates, and vegetation types for efficient treatment wetlands?
2. What is the capacity and longevity of a functioning system?

A pilot scale field experiment to investigate and develop design criteria was initiated in July 1986 at another seep on the Fabius coal preparation facility (Figure 10).

Relatively low construction costs, positive results, and the potential for long-term, maintenance-free treatment has justified five additional wetlands at the Fabius site and three wetlands systems at ash pond seeps at two TVA coal-fired stream plants. Preliminary, positive results are viewed with caution since a final assessment cannot be made until long-term data are available for analysis.

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MINE SEALING BY PNEUMATIC STOWING-- HELP FOR THE SMALLER CONTRACTOR

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INTRODUCTION

There have been many papers published on the subject of pneumatically backfilling underground mines and the sealing of entries to abandoned mines. This paper describes a different approach to pneumatic filling which is less costly and utilizes equipment which is more readily available to the small or medium-sized contractor. For example, the infeed bin has been designed to accommodate a front-end loader of 1-yard capacity and diesel-powered air compressors supply the conveying air.

Before discussing the improvements that have been made to the feeder unit, we will review the standard type of pneumatic stowing equipment that has been used for the past 20 years in the United States and its shortcomings when used for backfilling mine openings.

FEEDERS

The feeders most commonly used in rock conveying are of the rotary airlock type. Basically, this is a paddle-wheel rotor rotating between two side enclosures or "jaws". The jaws are adjustable to minimize the air gap between the rotor tips and the interface of the side jaws. As there is no give between the rotor tips and the side jaws, particles of rock are occasionally caught between. The feeder therefore has to be designed to withstand the shock of the rocks jamming. It is for this reason that the feeders are manufactured from massive parts and therefore are quite heavy which is not always conducive to mobility.

The flow material to a rotary airlock feeder must be controlled. This is either accomplished with a conveyor belt or vibrating pan feeder, both of which tend to make the material feedbin so high that only a large capacity front-end loader of 3- to 5-yard capacity can reach to discharge. As the average through-put of a mine backfill system is 30 to 50 tons per hour, such a large size loader is unwarranted.

AIR SUPPLY

Dilute phase pneumatic conveying requires relatively low air pressure which is most efficiently supplied by positive displacement blowers of the 2 or 3 lobe type. These machines produce large volumes of air, 2000 to 5000 ft³ per minute, at pressures of 12 to 18 psi, depending on the manufacturer. The blower is powered by a diesel engine for operating in remote locations. The disadvantage of this arrangement is that the diesel engine-blower has to be specially assembled and is not readily available for rent, or short-term leasing. It has a limited application, other than pneumatic stowing and will remain idle between projects.

PIPELINE

Pneumatic stowing systems which utilize positive displacement blowers to supply the air require large-diameter conveying pipelines to minimize the air pressure losses. It is common to use 8- to 12-inch-diameter pipes to maintain the running pressure within the capacity of the blower. Pipes of this size are difficult to assemble, especially in low coal mines.

The above disadvantages have been minimized in a newly developed pneumatic pipeline feeder, the TRITON 50, which is particularly useful for contractors due to its compact size and mobility.

TRITON 50 PNEUMATIC PIPELINE FEEDER

The TRITON 50 feeder is also of the rotary airlock type. However, there are no side jaws. These are replaced by a cylindrical Nihard casting, which is much less weight. The sealing between the rotor tips and the inner walls of the casting is achieved by using tips which are free to move radially and are kept in contact with the inner wall by means of springs. Should a piece of rock become caught between the rotor tip and the casting the tips will give sufficiently to allow this to pass. This arrangement also eliminated the need for adjustment when wear takes place.

A screw conveyor transfers the rock from the holding bin at a controlled rate to the rotary air lock valve. The screw allows for a bin design which is long and low in height and therefore suitable for filling with smaller size front-end loaders (e.g., 3/4- to 1½-yard capacity).

All these factors contribute to a smaller, more compact, lighter feeder unit which makes it more versatile.

A further development in the technique of pneumatically conveying rocks is the use of diesel compressors to supply the conveying air. Although the compressed air is supplied at 100 psig whereas it is only required up to 20 psig for conveying, there are several advantages in using compressors for this type of operation.

First, diesel compressors are usually available with contractors or can be leased on a daily or weekly basis. Two or more compressors can be coupled together to provide the quantity or air required, usually 1000-1500 cfm.

Secondly, the air from the compressors can be delivered through a 2-inch hose as the pressure drop along the hose does not matter significantly and therefore the compressors can be located at a distance from the TRITON operator.

Thirdly, as a result of using compressed air the conveying pipeline can be kept to the minimum size compatible with the maximum rock size. For example, if 2-inch rocks are to be conveyed, a 4-inch line is required. Whereas if 3-inch rock are to be conveyed, a 6-inch line is required. The pressure drop along the conveying pipeline is easily accommodated by the compressors. With a blower providing the conveying air the pipeline requires a cross-section of three to four times the maximum rock size.

Where the TRITON 50 feeder is installed in a tunnel or an underground mine it is convenient to operate the hydraulic pump for the screw and rotary valve with an air motor. The exhaust air from the motor is then utilized in the conveying line and does not exhaust to atmosphere and hence, waste. The hydraulic pump can also be powered with an electric motor, or more commonly for contractors' projects, utilizes a 20-HP gasoline engine.

The TRITON 50 feeder together with the hydraulic power pack, infeed bin, controls, etc. is mounted with a common frame. This in turn is welded to skids which enables the unit to be dragged over rough terrain. It is transported to the job site on a trailer hauled by a pick-up truck. Where suitable, the TRITON can be operated on the trailer. Alternatively it is removed from the trailer with the front-end loader and skidded to the operating site.

HELP FOR THE SMALL CONTRACTOR

How will this change in design of pneumatic conveying equipment help the small local contractor to successfully bid mine sealing projects?

- The TRITON is compact, self-contained, easily transported and relocated. It can be leased on a daily basis which eliminates capital investment in equipment.
- Diesel-powered compressors are usually an integral item in the contractor's equipment inventory or can be readily leased. The same applies to the 1-yard capacity front-end loader required to feed the TRITON.
- Four-inch-diameter pipes are inexpensive and require less labor to install than an 8- or 10-inch pipeline. Couplings for 4-inch lines are also cheaper, especially of the clamp-on variety.
- Help is available for the contractor from the minimum requirements of providing an operator to full assistance by our mining engineers on the techniques of pneumatic backfilling and sealing abandoned mines.

CONCLUSION

With the introduction of this new approach to pneumatic filling it is hoped that more consideration will be given in the future to this well-proven technique for sealing mine openings. This especially applies where the roof conditions are unsafe or dangerous gases may be present which precludes the entry of personnel into the mine for building stoppings by hand or other means.

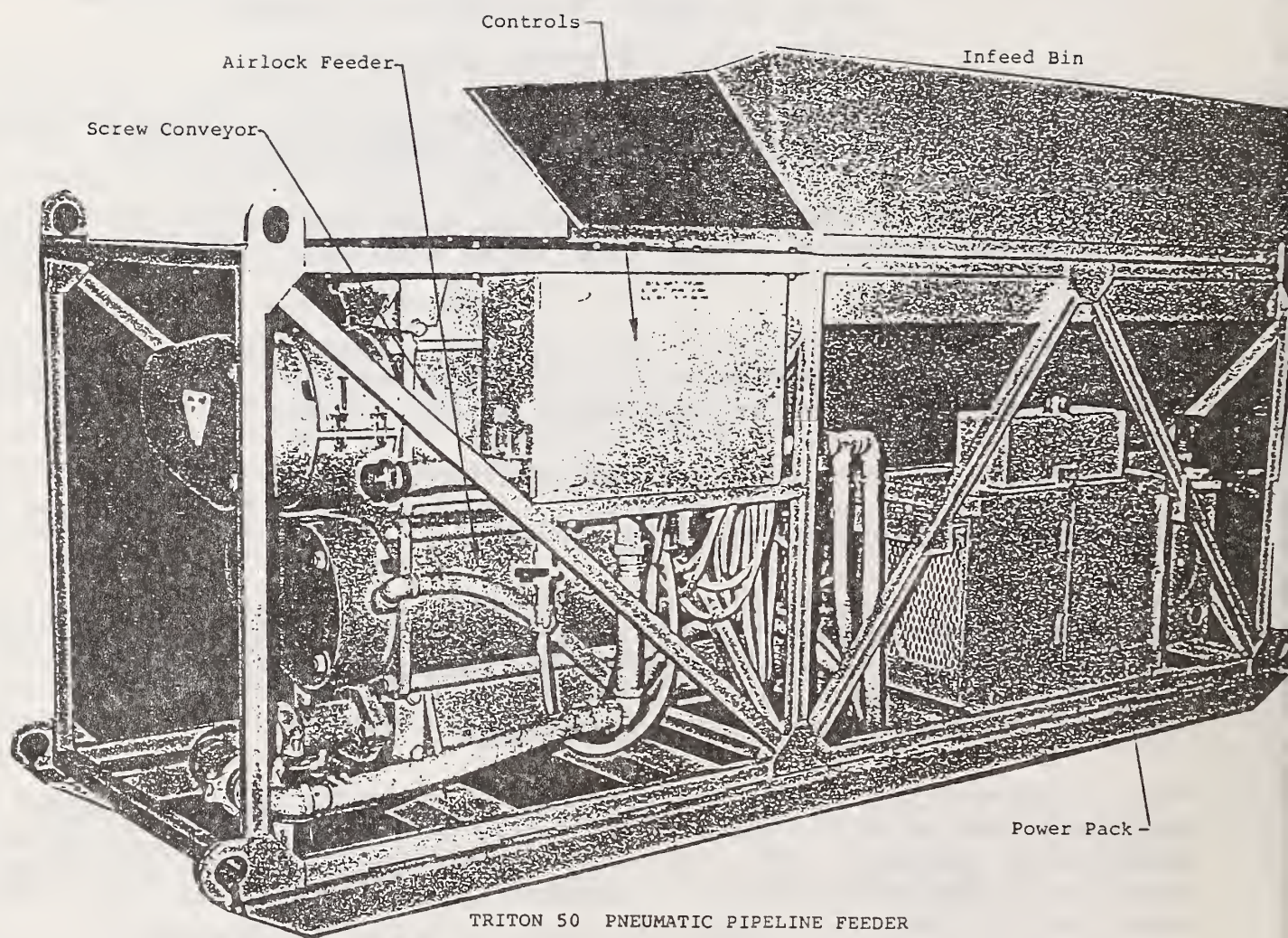


Figure 1. TRITON 50 pneumatic pipeline feeder.

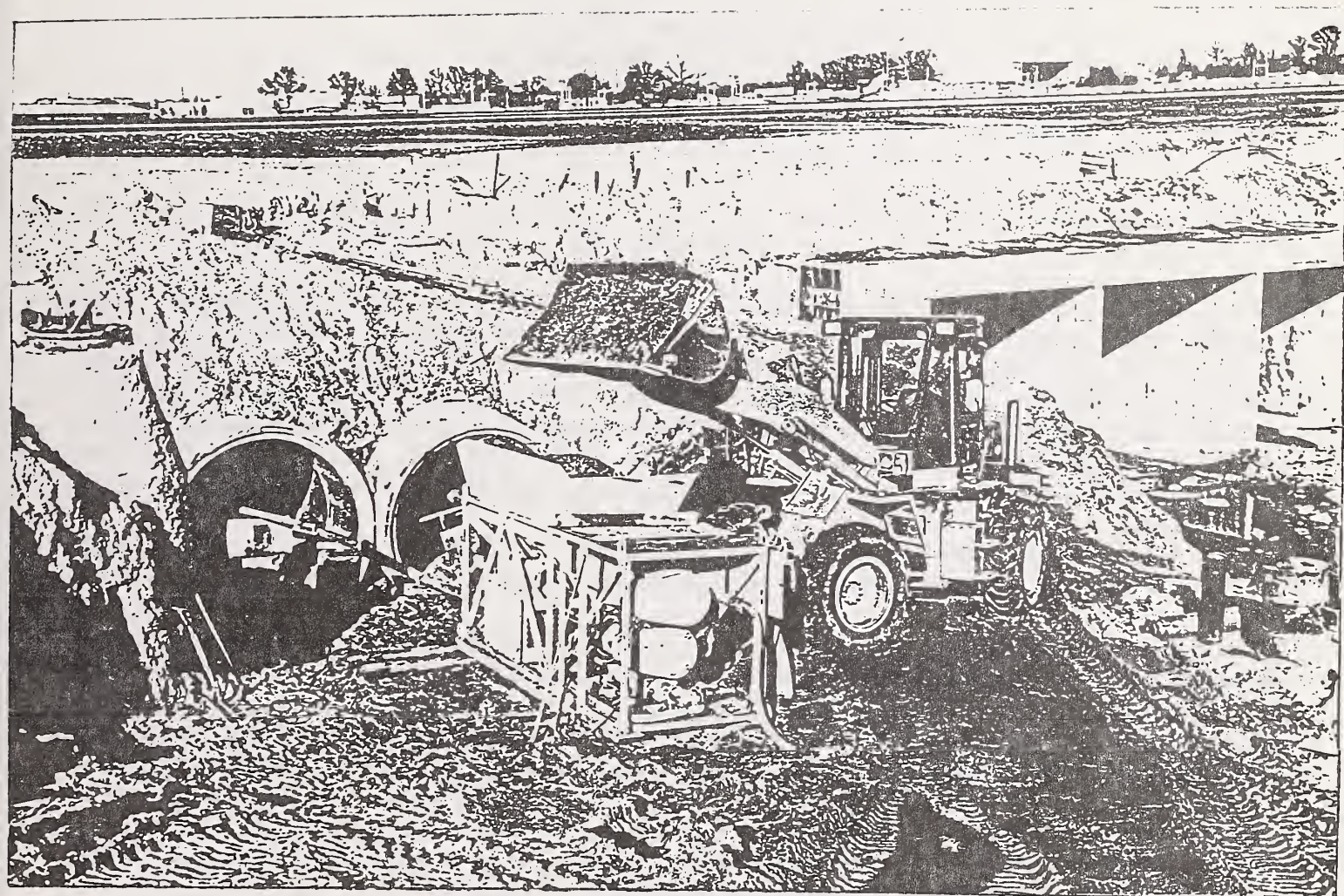


Figure 2. TRITON 50 backfilling abandoned tunnels.

REMOTE PNEUMATIC STOWING IN ABANDONED ROOM AND PILLAR MINES

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Abstract

SRW Associates Inc. recently completed a review of the state-of-the-art of remote pneumatic stowing for backfilling abandoned room and pillar mines. The review was performed for the Federal Office of Surface Mining Reclamation and Enforcement (OSMRE) which was providing technical assistance to the Pennsylvania Department of Environmental Resources (PADER). The PADER was considering the use of remote pneumatic stowing in an urban area where mine subsidence was frequently occurring.

The review included a study to determine the feasibility of using remote pneumatic stowing to abate mine subsidence in the project area.

After determining that remote pneumatic stowing could be a feasible method of mine subsidence control, SRW prepared a detailed set of technical specifications to permit project implementation. The specifications outlined requirements for an above-ground demonstration of the stowing system and the investigation of numerous areas, such as material trajectory, velocity, compaction and innovative elbow/nozzle configurations.

Since detailed mine maps of the area were unavailable, a thorough subsurface investigation was also performed utilizing expertise from OSMRE, SRW, and the PADER. The investigation, which utilized drilling and the Westinghouse borehole video camera, was performed in a systematic method which used borehole camera results to locate drill holes over mine voids. The effective use of the camera allowed the vast majority of the drilled holes to encounter mined areas.

SRW Associates Inc. is currently pursuing the general concept of remote pneumatic stowing. A program has been developed which would provide for researching and advancing the pneumatic stowing technology currently available.

INTRODUCTION

Stabilization of an abandoned mine to provide some measure of subsidence control and/or reduction is generally considered when surface facilities are or can be affected by mine subsidence. The provision of surface support lost by the removal of minerals in a deep mining operation is typically accomplished by one of two methods. Mine grouting is often used when the project purpose is to provide additional support to supplement the supporting mineral pillars. Total mine backfilling is implemented for a number of reasons. It is typically implemented when the mine voids to be backfilled are too large or too numerous to be stabilized by grouting. When total backfilling is desirable, hydraulic flushing is the method used most often.

Pneumatic stowing consists of using piped air flow to place material in underground voids. Remote pneumatic stowing, which is performed with all personnel on the ground surface (unmanned discharge), is a relatively new method for backfilling abandoned room and pillar mines. A borehole video camera is typically required to permit visual inspection of material placement. Remote stowing may only be implemented when the mine voids are open. It can be used to completely backfill large areas from a single bore hole, or to construct single support pillars in critical areas larger than those constructed by grouting methods.

This paper presents the results of a four-month study of remote pneumatic stowing and its applicability for stabilizing abandoned mines in western Pennsylvania. The state-of-the-art will be summarized, along with a discussion of a proposed demonstration project, as well as the methodologies used to map an abandoned mine using borehole photography. Due to funding problems, the proposed demonstration project has not been implemented.

PURPOSE OF DEMONSTRATION PROJECT

In December of 1984, the Office of Surface Mining selected SRW to evaluate the potential use of pneumatic stowing to backfill abandoned mines. The main purpose of the demonstration project was to determine the feasibility of the large-scale use of remote pneumatic stowing as a method to abate subsidence. Because it is a dry method, using only enough water to suppress dust, it could be very useful in dry, arid parts of the country that lack water, or in instances where site-specific conditions preclude the use of hydraulic fill and a dry backfill is desirable.

At the present time, the technology has not been developed to the point where remote pneumatic stowing is a generally accepted method of subsidence abatement. Therefore, a secondary purpose of the project was to advance the technology to the point where remote stowing could be considered a feasible method of subsidence control.

The proposed project area, a heavily developed urban area, was experiencing significant numbers of mine subsidence events. The decision to perform a demonstration program was based on the intent of OSMRE and PADER to:

- Advance the state-of-the-art of the technology.

- Provide an improved level of protection to the affected land owners in the proposed project area.

Mr. J. Eric Powell, P.E., a renowned expert in the field of pneumatic stowing, served as a member of the project team. As a consultant to SRW Associates, Inc., Mr. Powell made significant contributions to the project effort.

DEMONSTRATION PROJECT OBJECTIVES

To determine if remote pneumatic stowing was a viable method for large-scale backfilling in abandoned deep mines, a number of specific objectives were defined for the demonstration project:

Determination of Throw Distance: The horizontal distance that the material may be thrown underground using pneumatic stowing was the first variable to be determined. It was estimated that the economic viability of remote pneumatic stowing would be directly proportional to the distance the material could be thrown and the amount that could be stowed from a single borehole.

Estimation of Roof Contact and Roof Support: The amount of roof contact and roof support resulting from remote pneumatic stowing was to be estimated. The support would be a function of the degree of material compaction achieved. If a reasonable degree of roof contact and support could be provided, remote pneumatic stowing in abandoned deep mines would be deemed practical.

Effect of Material Types: The ability of pneumatic stowing to transport a wide variety of materials seems to be an inherent benefit allowing for a degree of feasibility in material selection. The relative degree of support provided by a variety of stowing materials would be further explored.

Estimation of Level of Effort Required: The level of effort associated with designing and implementing the project was to be determined. The cost of performing such a project would affect the consideration of future use of the method.

Advancement of Technology: A number of innovative procedures and equipment configurations would be required in the demonstration project. Development of new equipment was to be a part of the project.

Effect on Mine Subsidence: An attempt would be made to determine to what degree pneumatically stowing of mine voids might contribute to reducing the potential for mine subsidence damage. This was to be accomplished by extensively monitoring the demonstration project during implementation and investigating the effect of the stowed material on roof and rib support.

Further discussions on the objectives enumerated above are contained in other portions of this paper.

STATE-OF-THE-ART FOR REMOTE STOWING TECHNOLOGY

A thorough literature search was performed by SRW Associates Inc. for the state-of-the-art report. A number of undocumented pneumatic stowing case histories were also reviewed by direct contact with the firms involved. The following sections on equipment, capabilities, and limitations of remote pneumatic stowing were developed based on the available data.

AVAILABLE EQUIPMENT

Three essential components of a remote pneumatic stowing system are:

Pressurized Air Supply: A constant supply of air, of a sufficient quantity, and pressure to accelerate the stowing material and keep it moving through the pipeline at a high velocity.

Material Infeed: An airlock which feeds the stowing material at a controlled rate into the pressurized air stream with the minimum of air leakage.

Pipeline with Elbows and Nozzles: A pipeline to convey the material from the infeed to the discharge point. The pipeline must be of sufficient cross-sectional area to accommodate the larger pieces of material and avoid excessive pressure drop, especially if the pipeline is of a considerable length. The pipeline also typically includes elbows to change direction, either horizontally or vertically.

A schematic diagram of a remote pneumatic stowing system is shown in Figure 1.

Pressurized Air Supply

The air stream required for remote pneumatic stowing may be provided by either a positive displacement blower or by air compressors.

Positive Displacement Blowers

Positive displacement blowers provide an air source capable of supplying an air volume of up to about 5,000 cfm, at pressures up to about 20 psi with operational speeds of about 2,000 rpm. The blowers are typically powered by electric motors or diesel engines.

Positive displacement blowers provide the required air volume for remote pneumatic stowing at the lower capital cost, and are the least expensive to operate. They are, however, much noisier than air compressors.

Air Compressors

Stowing machines are currently being manufactured in this country which use compressed air at 100 psig to power the material infeed and to convey the material through the pipeline. The use of air compressors provides the following advantages:

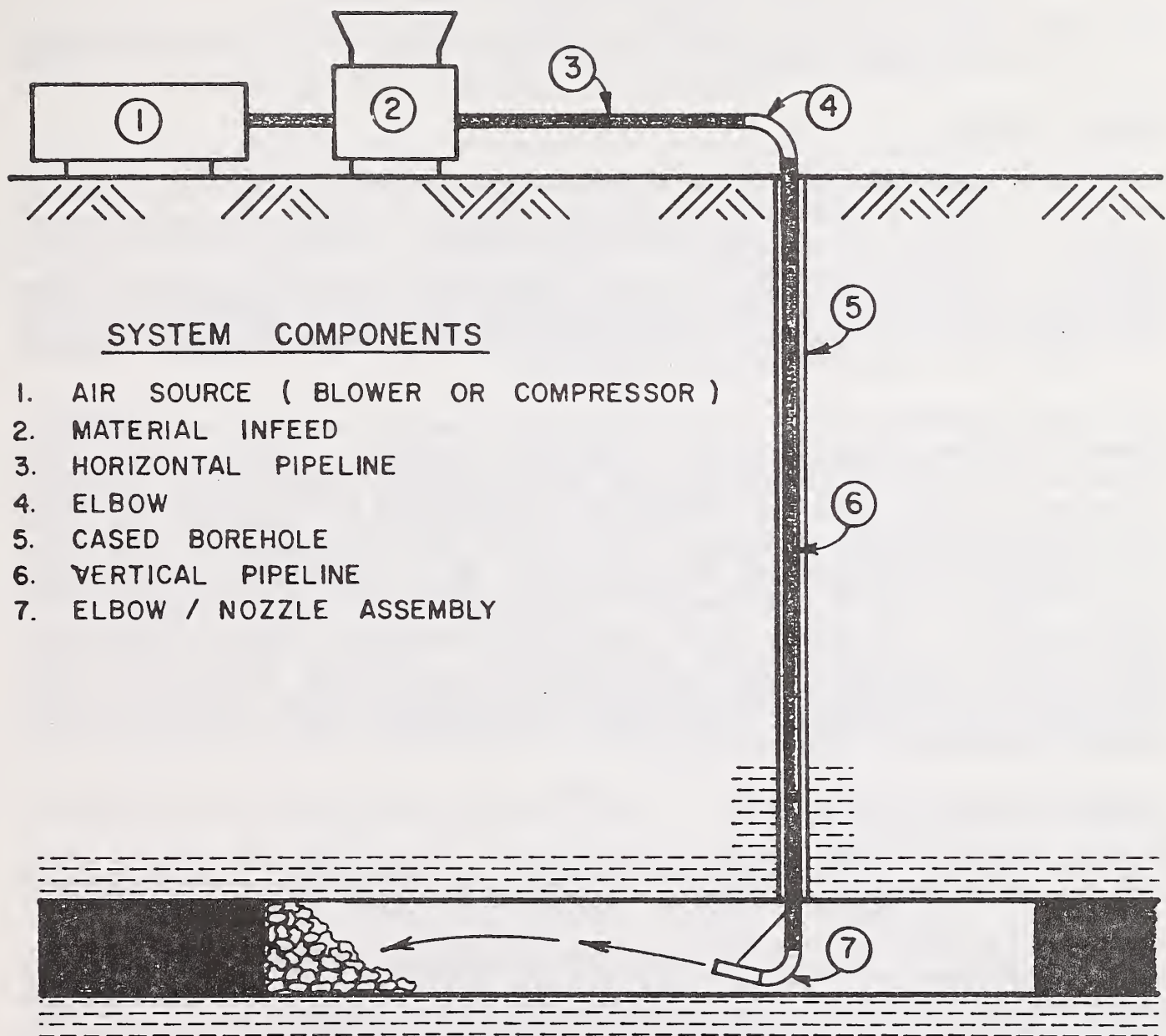


Figure 1. Remote pneumatic stowing system.

- Smaller diameter pipes can be used to convey a given quantity of material as a wider range of pressure is available to overcome the pressure drop resulting from the high velocity of the conveying air in the pipeline.
- Contractors typically own suitable compressors, or they may easily be rented, whereas positive displacement blowers cannot.
- Compressors may be coupled in parallel to provide the required air volume at the necessary pressure.

Material Infeed

An airlock feeder is required to introduce the backfill material into the conveying air stream without an excessive loss of air. Ideally, the airlock feeder should be capable of handling the largest particle to be conveyed, feed the material at a steady controlled flow, and allow a minimum of air to escape when operating. For conveying materials associated with remote pneumatic stowing, the component parts should be manufactured from abrasion resistant materials and when worn, should be easily replaceable.

The rotary airlock is by far the most popular feeder currently in use today. These units are simple, rugged, and easily maintained. The rotary airlock feeder is essentially a drum with open pockets around the outside, rotating in an enclosure with a close fit between the periphery of the drum and the inside face of the enclosure. Material is fed through the top opening in the enclosure, filling the pockets one at a time. As the drum rotates and the filled pockets reach the lower-most position, the material falls out of the pockets into the air stream. A rotary valve used for heavy-duty mining applications, especially for handling abrasive large particles, would be manufactured from castings of the hardest steel available with adjustments for wear. The feed wheel turns at a relatively slow speed, approximately 20 to 30 rpm, and is usually powered by a hydraulic motor.

Pipelines, Elbows, and Nozzles

Pipelines, elbows, and nozzles are required to convey the stowing material from the feeder to the mine, and to direct it in the mine.

Pipeline lengths for remote pneumatic stowing operations would not be expected to exceed 1,000 feet in length. Heavy-walled pipeline is recommended for the first 500 feet of the line, as excessive wear would be expected to occur in this section. In order to even out the wear, this pipeline should be rotated regularly. The required pipeline diameter is a function of the size of the material to be stowed. As a general rule, the inside diameter of the pipeline should be more than twice the size of the largest aggregate particle to be stowed.

The elbow/nozzle assembly is perhaps the most critical piece of equipment in the remote stowing system. The elbow/nozzle assembly must satisfactorily perform the following functions:

- Re-direct the stowing material in the mine void with minimal loss of particle velocity.

- Control the direction of the stowing material, both horizontally and vertically.
- Re-entrain the stowing material to provide maximum velocity, to minimize particle scatter, and to provide a high degree of material compaction.

The elbow/nozzle configuration is further confined by the requirement that it be capable of entering the mine void in a straight section through a bore hole. Once in the mine, the elbow/nozzle assembly must be formed into the configuration needed to convey the material horizontally.

Specific suggestions related to potential elbow/nozzle configurations will be presented later in this paper.

CAPABILITIES OF REMOTE PNEUMATIC STOWING

Remote pneumatic stowing operations possess inherent capabilities and provide a number of tangible benefits when compared to other types of mine backfilling systems. Some of the specific capabilities are as follows:

Materials

Pneumatic conveying systems are capable of transporting almost any type of dry or semi-dry soil or aggregate up to about 4-inch size.

The only kind of material that would be difficult to handle pneumatically is highly cohesive wet clay. This material would tend to plug the pipeline.

The flexibility in the type of material that may be stowed is a benefit that often enables the system user to choose the type of stowing material. This decision may be based on economics (ready availability of a specific material) or on desired support capabilities (cemented fill to provide maximum support).

Placement of Material Without Excess Water

Many backfill projects occur in mines where hydraulic flushing methods are not desirable or practical. In some geologic settings, the introduction of water into an otherwise dry mine may cause a number of problems. Interactions between excess water and some rock types in the mine environment may accelerate the rate of various subsidence mechanisms. The flushing water may also have to be handled after injection into the mine, which may sometimes be troublesome. Flushing in mines that drain to surface water courses might also cause a serious pollution problem.

In dry areas of the western United States, large quantities of water are not available to perform hydraulic flushing operations. This leaves pneumatic stowing as a desirable method of mine stabilization.

Material Throw Distance

A number of projects have demonstrated that a pneumatic stowing system is capable of throwing material up to 100 feet from the discharge nozzle, if directed at the proper trajectory and sufficient void height exists.

The long throw distance that may be achieved in a mine void is significant due to the large amount of material that may be stowed in the void from a single production bore hole. The capability to place a large amount of material from a single hole may prove to be beneficial by reducing the number of holes required to successfully perform a given project.

It must be remembered that no projects similar to the proposed demonstration project have, to the best of our knowledge, been performed in this country. The ability to throw material a long distance underground while in the "remote" mode using an elbow to redirect the material and a borehole video camera to monitor the operation has not been proven at the current time.

High Degree of Roof Contact

If the nozzle is properly directed, it is possible to attain continuous roof contact with the stowing material. A high degree of roof contact is certainly a priority in any type of mine backfilling operation. Generally, the better the stowed material contacts the roof, the higher the degree of roof support provided.

If close to 100% roof contact were achieved by a pneumatically stowed cemented fill, the potential for a damaging subsidence event to occur would be greatly reduced.

High Compacted Dry Densities

The ability to place material at a relatively high dry density, usually synonymous with the provision of roof support, has been demonstrated on a number of entry sealing projects.

High in-situ dry densities are likely to be achieved if the following factors are carefully controlled:

Throw Distance: maximum possible compaction is obtained with the distance nozzle some optimum distance from the pile face. This distance is probably significantly less than the throw capability of the equipment.

Velocity: Soderberg and Corson (no date given) have suggested that the maximum degree of compaction occurs when the aggregate is traveling at between 130 and 160 ft/sec.

Gradation: For optimum compaction, the stowing material should be well graded, with very little material minus the No. 200 sieve. Ten to twenty percent of the material should be in the 1½- to 2-inch size range, since the impact of these larger pieces provides the compactive force on the previously placed material.

Reduction of Roof and Pillar Deterioration and Provision of Lateral Support

In an unfilled mine void, air and moisture contribute to roof and pillar deterioration and spalling. The weakening and subsequent failure of the mine roof and supporting pillars is the major cause of mine subsidence.

A stowed mine void would provide some degree of protection from weathering to the mine floor and the supporting pillars. It could also lend support to the pillar and confine it laterally to reduce spalling, crushing or deformation.

While it would not eliminate the possible occurrence of a subsidence event, stowing voids should substantially reduce the risk and magnitude of subsidence events by providing roof and pillar support.

LIMITATIONS OF REMOTE PNEUMATIC STOWING

As with any backfilling operation, a number of limitations are associated with remote pneumatic stowing operations. Some of these limitations are due to a lack of detailed information on a number of important items. Some limitations on remote pneumatic stowing in abandoned room and pillar mines are as follows.

Mine Level Data Required

The high level of effort that may be associated with obtaining sufficient information on the mine level conditions at a proposed project area could be a limitation to pneumatic stowing in abandoned deep mines.

It is necessary to know the location, size, and condition of the mine voids that are to be backfilled. It is likely that the performance of extensive exploratory drilling and bore hole video surveys would be recommended prior to implementing most remote stowing projects in abandoned deep mines.

Void Size

At the current time, it appears that the size of the mine void to be stowed is another limiting factor on underground stowing. Small voids in the 2- to 3-feet-high range may not provide sufficient height to throw the material a worthwhile distance.

Stowing may be best suited for use in long, open mine voids because of the large amount of material that may be placed from a single bore hole. Mine voids smaller than about 10 feet in width, or 50 feet in length, are less suitable for pneumatic stowing methods.

The small amounts of material take that would result from the lack of void space might not warrant the cost of developing a production borehole. Voids of this type would probably be better stabilized by other abatement methods, such as fly ash-cement grouting.

Also, many types of experimental elbow/nozzle configurations are suited only for use in larger voids, in the range of 5- to 6-feet-high or higher. It may, therefore, be difficult to direct the stowing material in a small void.

Quality Control

The ability to consistently place material at a high degree of compaction has not been demonstrated at this time. The ability to do this in the remote mode is further complicated by the use of the re-directing elbow.

It is likely that material segregation will occur to some degree, regardless of the care taken in placing the material evenly. The segregation of the stowing material may result in varying in-place densities and, consequently, a variation in the amount of roof support provided.

The directional control of the elbow/nozzle assembly directly affects the support capability of the stowed material. It is not likely that voids of the size previously described as suitable for pneumatic stowing would present any physical limitations on horizontal or vertical control of the assembly. In order for the material to be compacted in-place, the stream of stowing material must be moved horizontally and vertically across the face of the pile. The impacting energy of the larger pieces tends to cause the compaction so, therefore, the material stream must be evenly directed across the entire face of the pile.

No attempts have been made, to our knowledge, to remotely control the throw direction of the material stream in a remote stowing program using bore hole video cameras to visually examine the stowing operation. The specific capability to control the material stream direction in the mine from the ground surface as desired has not been demonstrated, but is thought to be highly possible.

Water Conditions in the Mine

Pneumatic stowing operations may be used only in relatively dry mines. Pneumatic operations are obviously not suited for use in flooded mines.

Unknown Support Capability

As described in the literature review, detailed information on the relationship between roof support provided by stowed materials and reduced subsidence potential is unavailable.

Although not proven, it is thought that successfully stowing room and pillar mines may result in a major reduction in subsidence potential by adding lateral support to the pillars and providing some roof support.

It is also not known to what degree the compaction of the stowed material relates to the amount of roof support provided. More importantly, it is not known how much roof support needs to be provided to reduce subsidence potential. It is entirely possible that completely filling the voids with a loose, uncompacted aggregate may greatly reduce the subsidence potential. This would mean, of course, that obtaining a high degree of compaction may not be necessary to provide adequate support.

Material Availability

Where aggregates suitable for stowing are not readily available at a reasonable cost, pneumatic stowing may be too expensive an alternative to consider. Void stabilization by conventional partial grouting methods might, in a case such as this, be more cost-effective.

Unproven Ability to Throw Material in Remote Mode

As mentioned briefly in a prior part of this paper, no successful attempts have been made to cast the stowing material about 100 feet using a re-directing

elbow/nozzle assembly. Further attempts to do so should certainly be considered. It will call for the application of new technology, as it would require the development of a prototype elbow/nozzle capable of adequately re-directing the material.

If it was not possible to cast the material a significant horizontal distance, the resulting material pile would probably resemble an aggregate column similar to that constructed in some grouting operations. Currently used conventional methods of aggregate placement would probably be more cost-effective, if remote stowing could not throw the material horizontally a worthwhile distance.

POSSIBLE FUTURE USES IN AML PROJECTS

The future use of remote pneumatic stowing methods in abandoned mine lands reclamation projects may, to a large extent, be a function of the technical requirements of a specific project and the relative cost of stowing compared to the cost of other more conventional construction methods. The possible future uses of remote pneumatic stowing described below are based on possible technological capabilities.

Partial or Total Backfilling of Deep Mine Voids

At the present time, the lack of a suitable elbow/nozzle assembly prevents remote pneumatic stowing from being a useful method to fill and stabilize mine voids. If the material could be redirected in the mine void and cast horizontally, in addition to being both flexible and mobile as described above, remote pneumatic stowing should be a worthwhile method to perform the following.

Partial Mine Backfilling

When total backfilling has been determined to be unnecessary, predetermined dry mine voids could be filled to the extent required to provide partial roof support. By pneumatically stowing mine voids using cement and aggregate, it is possible to construct one-step cemented aggregate columns that have a greater roof contact area than those constructed by conventional gravel and grout methods. This may be a preferred substitute for grouted gravel columns currently being constructed.

Total Mine Backfilling

It may be possible to fill most identified large mine voids larger than 5- to 6-feet-high and 500 ft² in plan by pneumatically stowing material through a series of strategically located bore holes. As in partial filling operations, it may be possible to place a cemented fill providing a high degree of roof support. The effectiveness of this method in reducing the risk potential from subsidence events is not known at this time.

Prefilling Mine Voids and Subsequently Grouting

Pneumatic stowing may be feasible in prefilling mine voids with readily available, inexpensive aggregates prior to grouting. This type of operation should provide at least as much roof support as current conventional partial grouting methods.

REMOTE PNEUMATIC STOWING DEMONSTRATION PROJECT

PROJECT FEASIBILITY

After the review of the state-of-the-art of remote pneumatic stowing technology and the geologic and mining conditions in the proposed project area, it was necessary to assess the feasibility of the demonstration project. The project was assessed from both a technological and economic standpoint. Short discussions on each of these items are included below.

Technological Feasibility

It was estimated that the proposed demonstration project was technologically feasible, if a suitable elbow/nozzle assembly could be developed. The stowing equipment and expertise necessary to successfully perform the demonstration project was, for the most part, readily available. The technology required to develop a suitable elbow/nozzle was also readily available. It was concluded that a suitable redirecting assembly could be developed and fabricated without requiring a high level of effort or funding.

It was also concluded that while it may be technologically feasible and desirable in some cases to pneumatically stow abandoned mine voids, the effect of stowing on subsidence control had not been conclusively determined. The collection of data during the implementation of any demonstration project would be imperative if the effect of stowing on the amount of roof support provided was to be determined. If that could be accomplished, significant advances in the state-of-the-art of remote pneumatic stowing technology would likely result.

Economic Feasibility

The primary reason for implementing any type of stabilization project is the need to provide support to the mine interval, thereby reducing the subsidence potential. It was not possible to conclusively estimate to what degree remote pneumatic stowing in the project areas would reduce the potential risks of mine subsidence. The primary reason that it was not possible was the notable absence of information related to the support capabilities of pneumatically stowed materials.

It was concluded that pneumatic stowing was probably not cost competitive with other more conventional methods of mine stabilization. As with any new technology, certain additional costs were to be incurred to perform and evaluate the program. Since the unproven method was considered experimental in nature, production costs were expected to be greater than they would be if it was a common, established method. Additionally, significant data collection and evaluation had to be performed to determine exactly what benefits may be gained by pneumatically stowing mine voids.

Conclusions

Remote pneumatic stowing of abandoned deep mine voids was concluded to be a worthwhile and cost-effective method of mine subsidence control. The available technology, with some modifications necessary, appeared to be adaptable to the proposed demonstration project.

Prior to implementing the demonstration project, a suitable elbow/nozzle had to be developed. The required amount of mine level void space must also be identified.

Although the demonstration project was expected to incur significant expense, the potential technological advances appeared to far outweigh the project cost.

GEOTECHNICAL INVESTIGATION

As originally planned, the proposed demonstration project included remotely stowing approximately 10,000 tons of material in the mines underlying the project area. In order to accomplish this task, it was necessary to identify approximately 2,000 linear feet of open mine level voids.

Detailed mine maps of the area were not known to exist. Available bore hole data and frequent subsidence events in the area indicated that major areas of the mine had already collapsed. For those reasons, it became necessary to implement a comprehensive geotechnical investigation to identify the available amount of mine level voids.

The geotechnical investigation utilized a systematic approach of drilling and bore hole video photography to identify sufficient quantities of mine level voids.

Methodology

The investigative program was carried out under the direction of SRW's full-time project representative whose responsibilities included directing the use of the bore hole video camera to obtain the data required to plot the mine configurations, and identifying potential bore hole locations based on the bore hole camera surveys. The bore holes were installed under the supervision of PADER's field representative.

The general procedural approach to quantifying mine level voids initially involved using a compass-equipped bore hole camera and a light source in existing bore holes to estimate the dimensions, heading direction, and interconnection of the voids penetrated by these holes. The interconnection of voids was determined by the use of a camera at one mine void location and a mine safety light and/or fluorescent tube light dropped into the mine from other bore holes close by or along the same void orientation. Exploratory drilling, which commenced shortly afterward, consisted of locating the drill rig at various distances from the initially observed void locations along estimated void lines. A void encountered at a new drill location would then be observed with the bore hole camera to estimate its dimensions, heading direction, and interconnection with other voids. The drill rig would then be relocated in line with that void's orientation and the procedure repeated. This technique was used to "chase" interconnected voids for as long as possible, i.e., until the void either terminated, collapsed, or changed direction.

Results

Approximately 2,500 linear feet of open mine workings were identified during the exploratory program based on the extent of actual and project mine level voids shown in Figure 2. Based on the bore hole camera surveys, nearly all

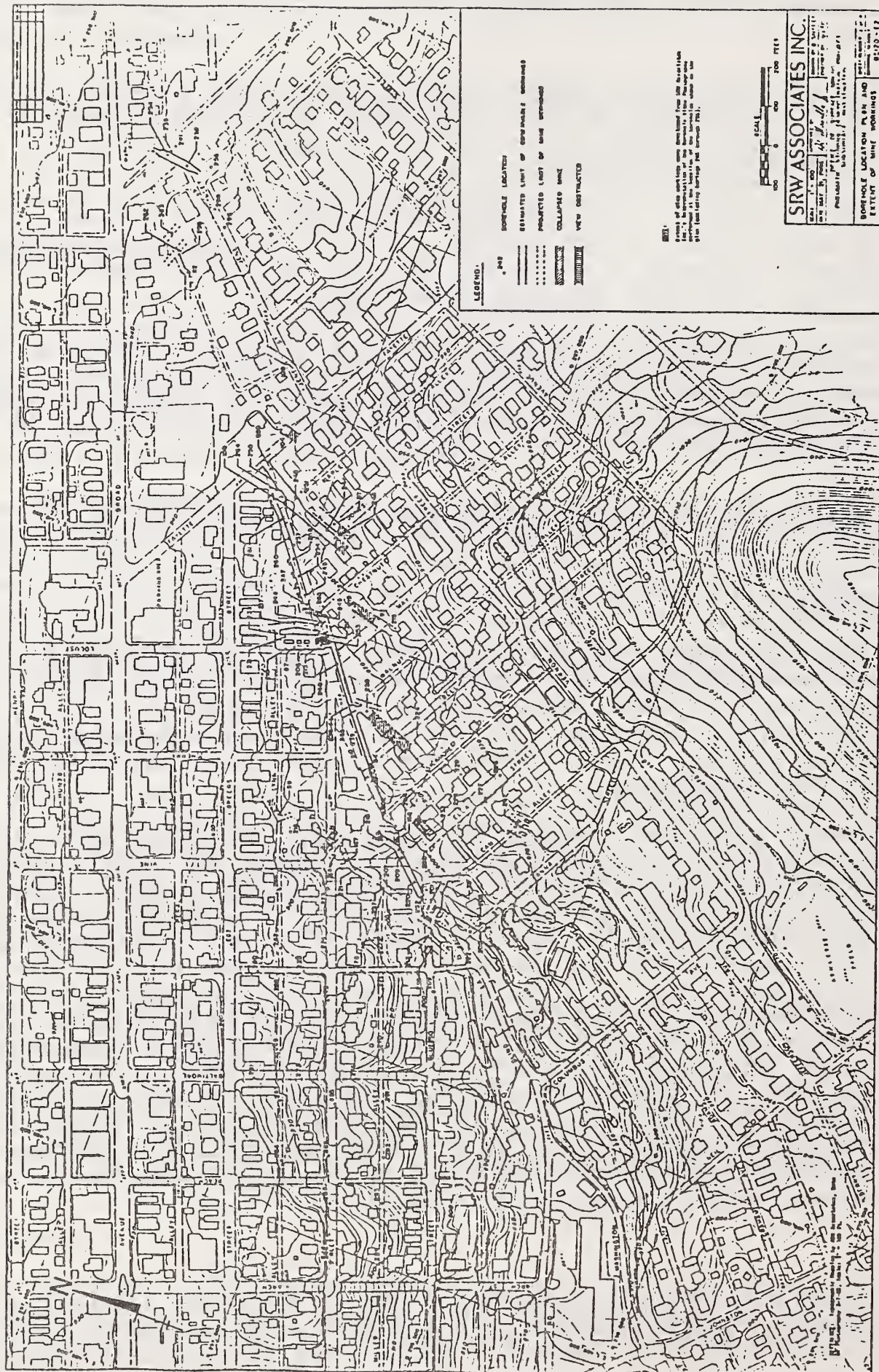


Figure 2. Borehole location plan and extent of mine workings.

of the voids had some amount of roof fall material on the floor. The height of these voids often varied depending on the extent of the roof fall and the amount of collapsed material on the floor. In addition, the height of the void at the point where the bore hole penetrated did not always reflect the average height of most of the surrounding void, which was often greater. Therefore, an effort was made during the camera surveys to estimate a void height which was representative for most of the void. The widths of the voids were estimated to range from a minimum of 10 feet to a maximum of 37 feet, while the longest continuous voids encountered were over 300 linear feet in length. The axis of most of the voids was, for the most part, in either a northeast-southwest direction or northwest-southeast direction.

Conclusion

Based on the locations, dimensions, and continuity of the open mine workings observed, it appeared that the proposed project area was suitable for use in the remote pneumatic stowing demonstration project. A construction plan, indicating the location of production boreholes and observation boreholes, and the proposed stowing directions, was developed and is included as Figure 3.

PROPOSED PROJECT WORK PLAN

General

A large number of system variables, such as operating capacity and type of material to be stowed, were selected during the design of the proposed demonstration project. The demonstration project was to basically consist of throwing and monitoring a number of different stowing materials. The stowed material would subsequently be evaluated to estimate the degree of material compaction and amount of roof support.

The success of the demonstration project would depend to a large degree on the equipment and expertise of the selected contractor. To certify that the selected contractor possessed both the necessary equipment and expertise, the contractor was to be required to demonstrate the capabilities of his equipment at an above-ground location prior to being permitted to mobilize to the project area.

The proposed sequential work plan described later in this section generally outlines the specific approach proposed to perform the remote pneumatic stowing demonstration project.

Stowing System Requirements

A number of stowing system requirements were developed. The requirements were those minimum physical requirements deemed necessary to perform the project. The system requirements were selected based on the following:

Estimated Throw Distance: An estimated maximum possible throw distance of 100 feet. The stowing material would just contact the roof of the mine void at a 50-foot distance.

Void Height: An estimated minimum workable mine void height of 5 to 6 feet.

Particle Size: Maximum size of the stowing material was estimated to be in the 2-inch size range.

Particle Velocity: The required discharge velocity of a large aggregate particle for it to travel the maximum distance was 100 fps.

Based on the above assumptions and estimates the following system requirements were recommended:

System Capacity: The contractor's equipment was to be capable of sustaining stowing of a minimum of 50 tons of material per hour and was also to be able to operate up to 75 tph. Considering the likely size of the mine voids present in the project area, the authors felt that a larger system capacity would not allow sufficient time to evaluate on-going stowing operations.

Pipeline Size: The above-ground pipeline and the pipe in the bore hole to the elbow was to have a minimum inside diameter of 5 inches.

Bore Hole Size: The production bore hole was to be cased with at least an 8-inch-diameter casing.

Airflow Velocity: The air source was required to be capable of conveying the air through the pipe at an average velocity of at least 350 fps.

Proposed Work Plan

The sequential work plan prescribing the major items necessary to perform the demonstration, from elbow fabrication to below-ground demonstration, was developed. The proposed work plan is described below.

Elbow/Nozzle Fabrication

The first work item to be performed by the selected contractor was to be the fabrication of selected elbow/nozzle configurations. The elbow/nozzle designs proposed are discussed later in this document. These elbow/nozzle assemblies were to be tested in the above-ground demonstration. The elbow/nozzle combinations judged to be capable of providing the desired result were to be incorporated into the proposed underground phase.

Above-Ground Demonstration Project

After the contractor fabricated various elbow/nozzle assemblies, he was to perform an above-ground demonstration of the physical plant to be used in the demonstration project. The purpose of this demonstration was to verify the capabilities of the contractor's proposed physical plant, to test the elbow/nozzle assemblies, and to compare the planned trajectory-velocity relationships with the actual. The specific objectives of the above-ground demonstration are outlined below.

Demonstration of Capacity: The contractor's physical plant would be inspected and operated. The contractor would be required to successfully demonstrate his equipment by stowing 50 to 75 tph of project refuse

through a straight pipeline. The length and diameter of the pipeline was to be specified in the contract documents.

Elbow/Nozzle Testing: If the contractor was successful in demonstrating his equipment, the fabricated elbow/nozzle assemblies would be tested. A portion of the pipeline was to be raised in order to simulate remote stowing through a vertical bore hole.

Verification of Velocity-Trajectory Relationships: The elbow/nozzle assemblies were to be evaluated based on their actual velocity-trajectory performance, as related to the estimated relationships. Assemblies judged to be successful were to be used in the actual underground remote stowing operations.

Test for Distance: The maximum possible stowing distance the contractor's equipment was capable of achieving was to be estimated. The maximum height of the material stream for any given material throw distance was also determined.

Testing for System Blockage: The stowing material would be tested at various moisture contents, both with and without cement added. This was thought to be necessary in order to identify any potential problems with the system blockage.

Proposed Remote Stowing Demonstration Project

If the contractor was judged to possess the required equipment and expertise, and suitable elbow/nozzle assemblies were developed, his equipment was to be mobilized to the project area and the below-ground phase would begin. The program would be performed in such a manner that the following items could be evaluated.

Material Throw Distance: The maximum attainable material throw distance, as a function of the stowed void height would be determined. It is estimated that the ability to cast the material significant horizontal distances (up to 100 feet) would have been demonstrated.

Effect of Various Elbow/Nozzle Assemblies: The effect that the tested configurations have on material throw distance and compaction would be determined.

Testing of Various Materials: Some or all of the aggregates listed below should be used in a demonstration project in an attempt to determine the effect of material type on throw distance and compaction results:

- coal refuse (2-inch maximum)
- coal refuse (1-inch maximum)
- slag (minimum 2.4 SG)
- reddog (2-inch maximum)
- "dirty" river run sand and gravel
- well-graded crushed stone

Stowing with Cement Additives: The use of Portland cement as an additive should be included in a demonstration project. The use of cement

with both coal refuse (2-inch maximum size) and crushed stone of the same maximum size should be considered to allow the evaluation of the effect of cement on increased roof support.

Effect of Moisture Content on Compaction: The moisture content of one moisture sensitive stowing material should be varied in different trials. The evaluation of the effect of moisture content on compaction and roof support should result from this type of experiment.

Effect of Placement Control on Compaction: The importance of controlling placement needs to be assessed. Using only one material, both tightly controlled and loosely controlled placement should be performed and evaluated.

AREAS REQUIRING ADDITIONAL STUDY

During the development of the state-of-the-art review for remote pneumatic stowing, it became evident that additional research on a number of subjects must be performed and evaluated in order for remote pneumatic stowing to be more thoroughly evaluated as a method of mine subsidence control. The following items requiring additional study are listed in descending order of importance:

- Elbow and nozzle design for remote stowing.
- Effect of material type, gradation and moisture content on mine roof support.
- Use of video equipment for monitoring stowing operations.
- Use of compressed air.
- Effect of material type on system wear.

If the demonstration project would have been implemented, a number of variables in the first three items would likely have been evaluated.

ELBOW AND NOZZLE DESIGN FOR REMOTE STOWING

General

One of the advantages of remote pneumatic stowing is that the material may be discharged from the pipeline at a velocity up to 120 mph. The high velocity could result in compaction of the material, especially when the fill material contains a quantity of larger material in the 1½- to 2-inch size or even up to 3-inch size that impact into the stowed faces.

It may also be possible to cast the material significant horizontal distances in a mine void. Where the vertical height is limited, for example, underground in a 6-foot-thick mined coal seam, the trajectory distance could possibly be about 100 feet. To achieve the maximum trajectory distance possible, the discharge

nozzle should be at floor level and inclined upward slightly so that the material at the highest point in the trajectory just skims the roof. The calculations and a drawing related to this conclusion are shown in Figure 4. As dictated by the law of physics, to achieve a longer trajectory, the velocity of the material leaving the nozzle must be increased. This can be achieved by increasing the velocity of the flowing air in the pipeline.

Elbows

Remote pneumatic stowing pipelines will generally change direction, both horizontally and vertically, by using elbows. The stowing material will impact on the outer radius of the elbow. As a result of the impact, the material emerges from the elbow at a much lower velocity than its initial velocity. The material is generally re-accelerated to the normal conveying velocity over the next 30 to 50 feet of straight pipeline beyond the elbow. Therefore, in remote pneumatic stowing where compaction is important or the material has to be thrown a considerable distance into the void, at least 50 feet of straight pipe is generally required to re-entrain the material and achieve the maximum conveying velocity. In backfilling an underground mine by remote stowing, it is not possible to have such a length of pipe following the elbow. The elbow and discharge nozzle will be required to form one unit and be suitably designed to permit the lowering of the unit through a suitably sized bore hole for the blind stowing mode.

The concentration of the stowing material into the directable stream is required in a blind backfilling program. The following preliminary elbow/nozzle designs were considered for demonstration as part of a remote stowing program.

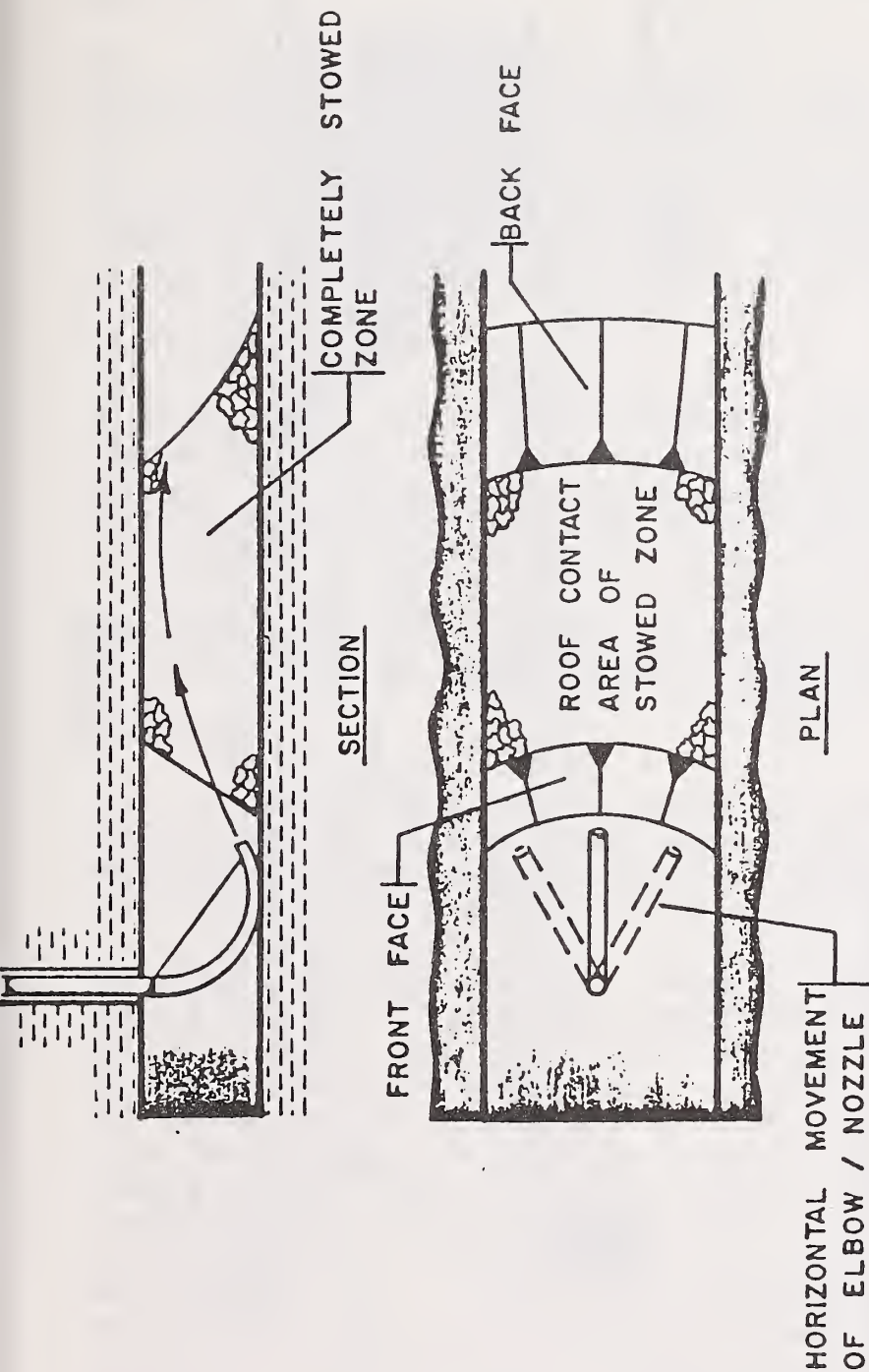
Rubber Hose

The simplest design for an elbow which can readily be straightened to fit down the bore hole casing is a rubber hose. The discharge end of the hose is attached to a steel wire which is lowered down the bore hole with the material pipe. When the hose end has reached the floor of the cavity, the wire is pulled up leaving the hose to form a radius. A 10-foot length of the hose may be attached to the material conveying pipe. Alternatively, the hose may extend from the surface through the bore hole to the underground cavity. In either case, sufficient length of flexible hose is provided to allow a radius to be formed at the bottom of the bore hole.

The disadvantage of using a rubber hose as an elbow is the high friction factor which will result in a lower velocity of the material discharging from the open end. In addition, the backfill material, especially if it consists of crushed rock or other sharp material such as reddog, will cut into the inner lining of the hose and create a wear problem. Material conducting hose constructed of the best quality available needs to be considered if an economic life is required. A drawing showing this type of elbow is shown on Figure 5.

Segmented Steel Elbow

A segmented steel elbow was preliminarily designed with segments manufactured from square steel tubing with the ends cut to an angle of $7\frac{1}{2}^{\circ}$. The segments are attached to each other through hinged pins welded to the longest side of each segment. Six such segments, approximately 9 inches long, will make up



THEORY OF MATERIAL THROW DISTANCE

- Assume:
 - 1,800 cfm Air Supply
 - 5 in. ID Line (0.136 sq. ft. area)
 - Material Velocity = 404 Air Velocity
 - Bore Hole 50 ft. Deep, Entry 6 ft. High
 - Material Velocity Leaving Top Elbow = 50 ft./sec.
- Velocity of Material Entering Elbow at Bottom of Bore Hole = Velocity Due to Gravity Plus Air Conveying Velocity

$$V_E = V_G + V_H$$

$$V_G^2 = V^2 + 2 gh$$

$$V_G^2 = 50^2 + 2 \times 32.2 \times 50$$

$$V_G^2 = 2,500 + 3,220$$

$$V_G = \sqrt{5,720}$$

$$= 75 \text{ fps}$$

$$V_H = 75 + 116 = 191 \text{ fps}$$
- Velocity of Material Leaving Elbow at Bottom of Bore Hole:

$$V_L = 0.5 V_E$$

$$= 0.5 \times 191 \text{ fps} = 95 \text{ fps}$$
- To Elbow Roof, Assume Trajectory 5 ft. High (6 ft. Coal Seam)

$$\text{Height of Fall} = 1/2 gt^2 \quad \text{OR} \quad t = \sqrt{\frac{2h}{g}}$$

$$t = \sqrt{\frac{2 \times 5}{32.2}} = 0.557 \text{ seconds}$$

Velocity of material on leaving nozzle will be reduced by resistance of air, say to 90 fps, from 95 fps in "half" trajectory:

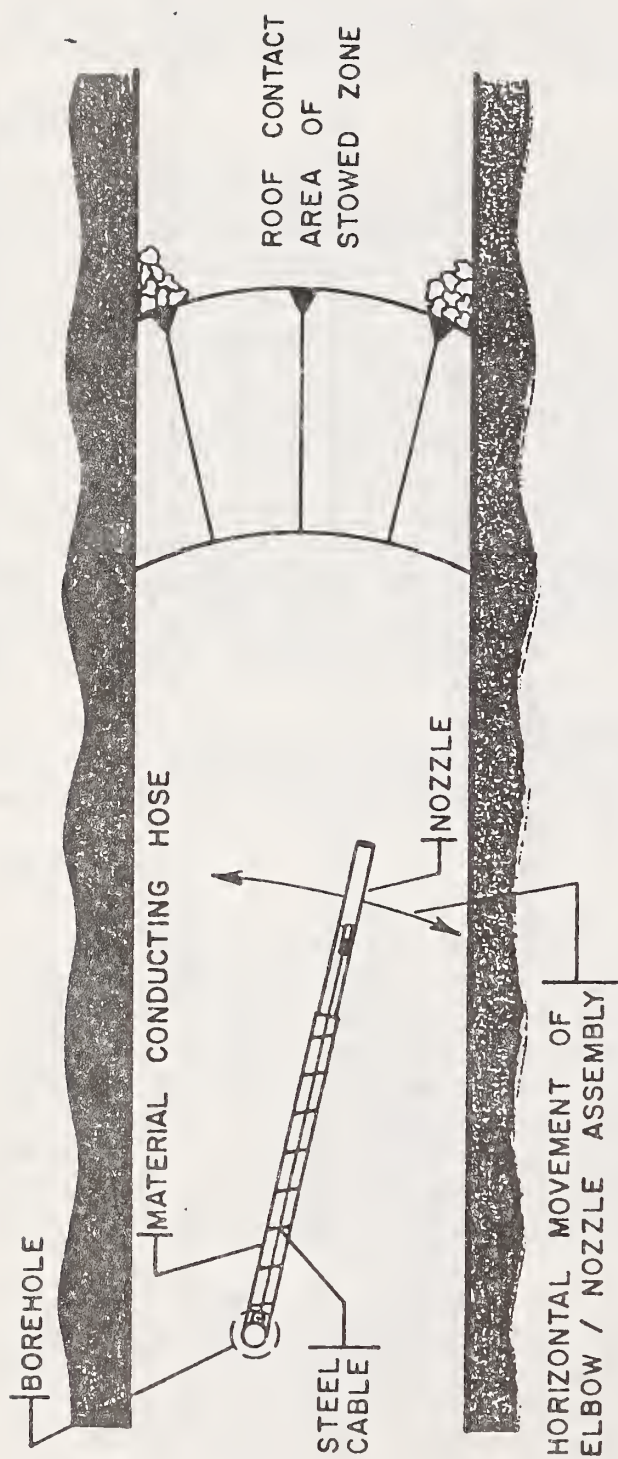
Horizontal Distance = Velocity of Material $\times$ Time to Fall

$$= 90 \times 0.557$$

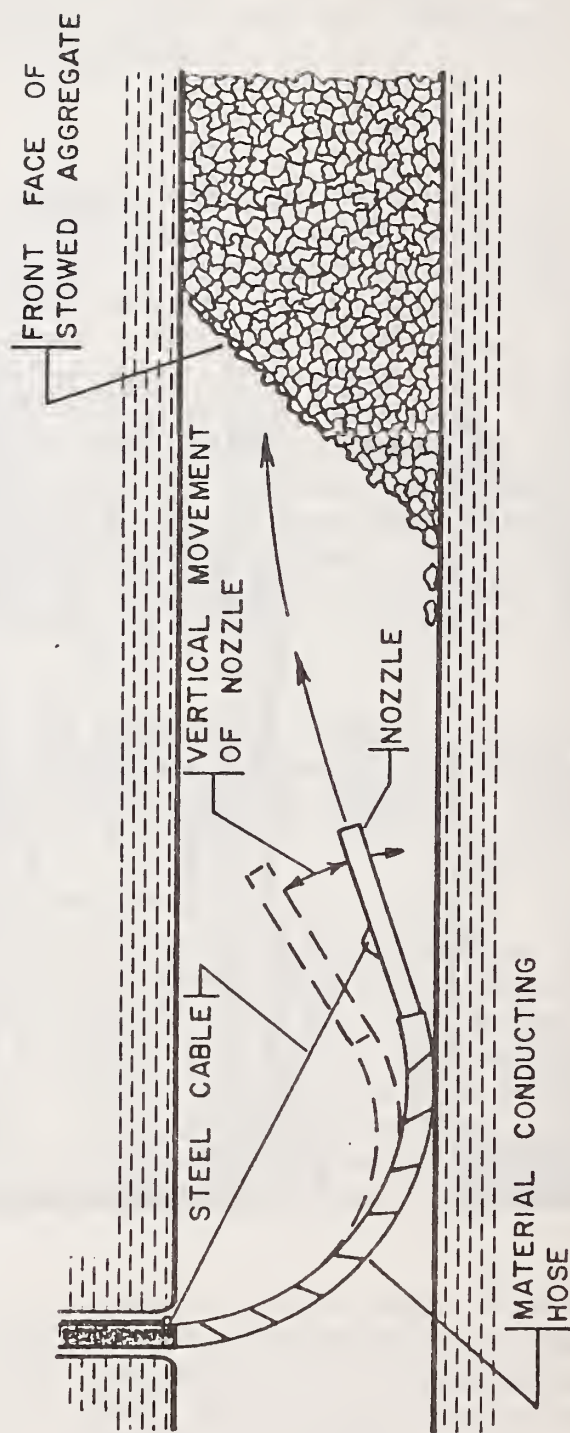
$$= 50 \text{ ft.}$$

Material thrown 100 ft. from nozzle for 5 in. I.D. pipe and assumptions above, if nozzle at or near floor level.

Figure 4. Theoretical material throw distance.



PLAN



SECTION

Figure 5. Flexible elbow/nozzle assembly.

a 36-inch-radius, 90° elbow, when the angled ends of each segment are butted together. This could probably be achieved by a steel wire cable attached to the end of the discharge segments and be pulled upwards when the segmented elbow has entered the mine cavity. Without tension in the steel wire cable, the segments will hang free in a vertical position and could be lowered down the bore hole.

The disadvantage of a segmented steel elbow is that all the segments must be butted together to form the elbow and, although the elbow angle can be varied from 90° to 110°, control of the trajectory of the fill material can only be made by adjusting the angle between the segments. An adjustment in this angle could not be made without opening the interfaces between the segments, which would increase air loss. This can either be ignored, or a rubber gasket glued to each face. A drawing of this type of elbow is shown in Figure 6.

Short Radius Elbow

A short radius elbow which utilizes a blind tee configuration is shown in Figure 7. This elbow/nozzle could be lowered into the bore hole in a free hanging vertical position. After entering the mine void, the control cable could be pulled taut. When the cable is tightened, the nozzle would be pulled into position and would align itself with the blind tee.

The nozzle could be designed with an overall taper, or with a slight elevation in the lower half to provide greater concentration of the material stream.

Summary

The efficiency of any of the previously described elbow/nozzle assemblies in directing the fill material is unknown at this time. It is not known if uniform material distribution along the mine roof may be accomplished. The effect of fill distribution on the provision of roof support should also be evaluated.

Assuming a satisfactory elbow could be developed to permit the material to emerge from the discharge at a sufficiently high velocity to throw the material 100 feet into the mine entry from the bore hole, then the material has to be directed to the sides of the entry. This could probably be achieved by rotating the material conveying pipeline in the bore hole. When the backfill material is being thrown the maximum distance, the elbow has to be only moved a small increment to cover the full width of the entry. As the stowed material progresses along the entry toward the elbow, the angle of side to side movement would have to be increased and in the final stages may require a movement through 180°. This angle of increment could be accommodated on the surface with some form of swivel coupling within the conveying pipe. On completing the filling of the entry to one side of the bore hole, the elbow could be rotated to face the opposite direction and backfilling could be resumed.

Nozzles

General

As previously described, a tapered nozzle should be beneficial in concentrating the discharged material into a stream. A number of variables in the nozzle

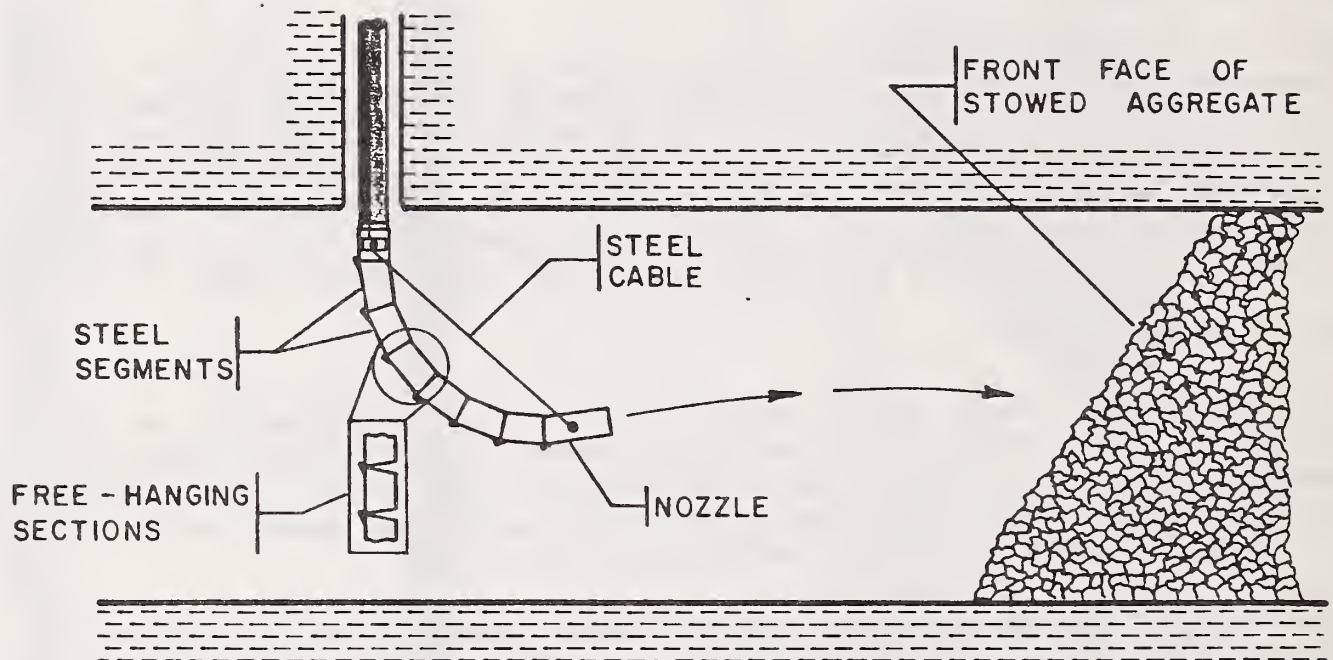


Figure 6. Segmented elbow/nozzle assembly.

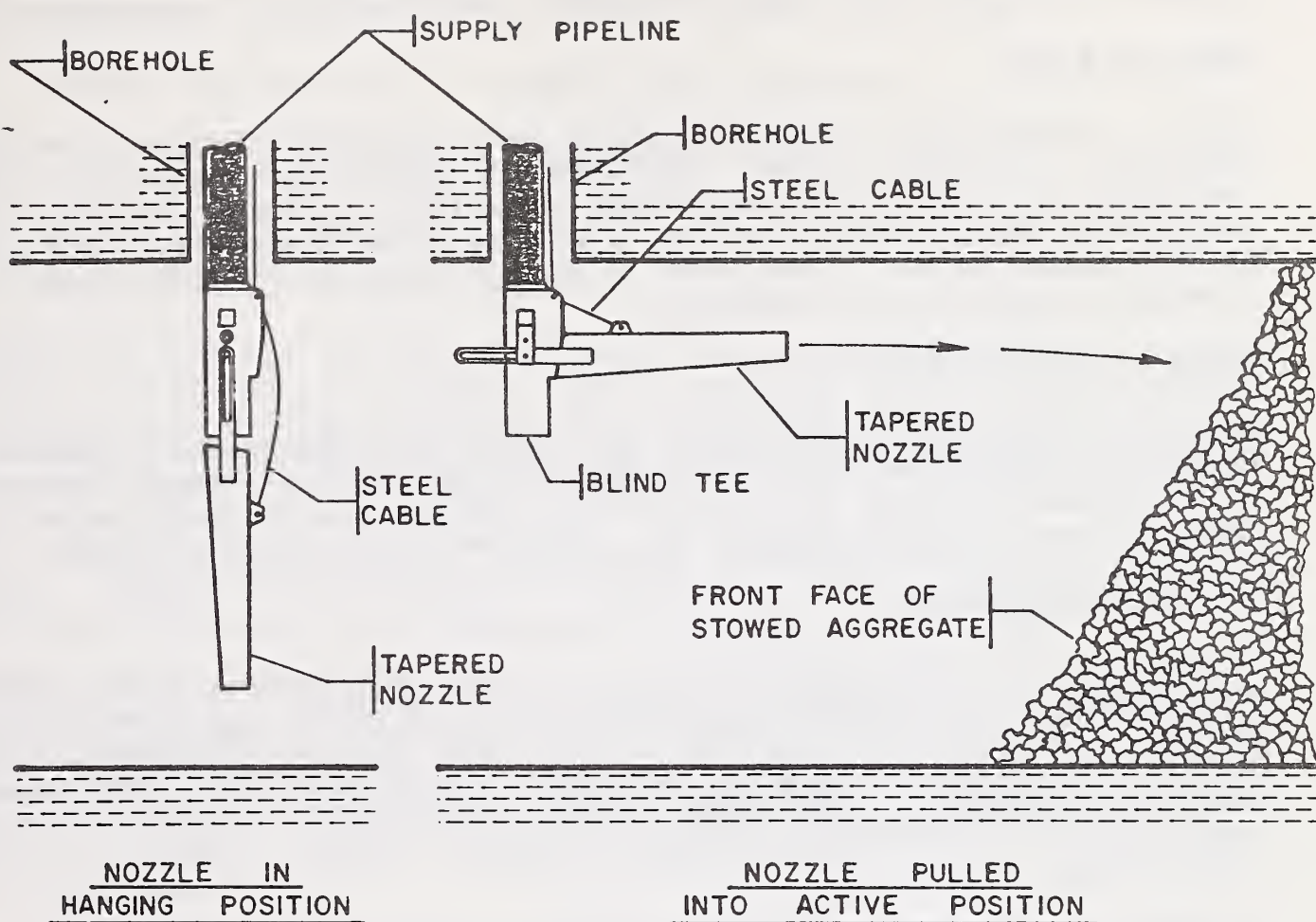


Figure 7. Short radius elbow/nozzle assembly.

design, such as the degree of taper and nozzle length, require further research to determine their effect on material concentration and compaction.

Effect of Taper

Slightly tapered nozzles have been proven to be somewhat effective in reducing the amount of material scatter. The degree of nozzle taper would likely affect the ability of the nozzle to concentrate the material. Further research needs to be performed to identify the best degree of nozzle taper based on the size of the stowed material. The effect of a tapered nozzle on system power requirements should also be determined.

Effect of Nozzle Length

Variation in the nozzle length for a fixed inlet and outlet diameter affects the degree of nozzle taper. As previously mentioned, further research needs to be performed in order to determine the optimum nozzle configuration that improves maximum throw distance and compaction of the stowed material.

Internal Configuration

No research has been performed to date related to the effect of the internal configuration of the nozzle on its ability to concentrate the material into a stream. Most nozzles have smooth internal walls. The use of a ribbed configuration in the nozzle, similar to that used in a flatback elbow, may warrant further investigation. The ribbed configuration may provide greater concentration of the material stream through its possible "lifting" effect on the material particles.

EFFECT OF MATERIAL TYPE, GRADATION AND MOISTURE CONTENT ON MINE ROOF SUPPORT

General

The purpose of remote stowing is to provide secondary support to the mine roof adequate to support the overburden load.

The ability to place high-density fill tight to the mine roof should indicate that roof support be provided. However, pneumatically stowed material will probably not provide 100% support of the roof. The stowing material, however, should reduce pillar weathering and spalling, which results in reducing pillar support to the mine roof as the sectional area decreases. The important aspects of backfilling are to support the pillars, reduce the flow of air through the mine workings to reduce oxidation or weathering, and reasonably fill the voids to reduce further subsidence. Pneumatic backfilling may achieve these objectives more efficiently than hydraulically placed fill under given conditions.

Material Type

Some hard aggregates, if highly compacted, can provide a higher degree of roof support than softer, compressible materials. A variety of materials possessing different physical characteristics should be stowed in a demonstration program so that the different roof support capabilities can be evaluated.

The amount of wear occurring in the system is a function of a number of different system variables:

- Material composition of the stowing system equipment.
- Volume of material conveyed through the system.
- Velocity of conveyed material.
- Abrasiveness of conveyed material.

Considering all other variables to be equal, the major determining factor in the amount of wear in a given system is the abrasiveness of the conveyed material. In underground stowing operations, the abrasiveness of various materials likely to be stowed may qualitatively range from fairly abrasive (coal refuse material) to highly abrasive (crushed stone or slag).

The abrasion on system parts will have an economic impact on any stowing project through the replacement of worn parts. The cost of "down time" during equipment repair and maintenance must also be considered.

Complete cost data from a number of projects using different fill materials should be analyzed to determine if it is economically feasible, from the standpoint of equipment maintenance costs, to pneumatically backfill underground mine voids in the remote mode. The analysis may indicate that it is more feasible to stow one type of material than another with respect to system wear.

FUTURE PLANS

SRW Associates Inc. is currently developing plans to further research a number of these items. It is hoped that this research will advance the currently available technology to the point where remote pneumatic stowing will become a routinely used method of mine stabilization.

SUMMARY

In the opinion of the authors, remote pneumatic stowing is a method of subsidence abatement that has high potential that has yet to be realized.

The inherent benefits of the method, as previously described, present strong arguments for the funding of additional research to advance the technology. The area of the technology that requires the most advancement, the elbow/nozzle assembly, can probably be developed without significant cost.

The potential success of this method has been realized by a small number of private firms and governmental agencies. These organizations have already done a great deal to advance the technology to its present state. It is hoped that we will continue in our endeavor, which is to develop remote pneumatic stowing to the point where it is routinely used in subsidence abatement.

Use of Borehole Video Camera During Filling

When stowing is in progress, the operator will need to know when the material is being placed across the full width of the entry up to the full height, including roof cavities above the fallen slabs of rock. The borehole video equipment can be used for this purpose providing airborne dust is kept to a minimum.

Camera Placement

The camera ideally should be mounted at the nozzle to view the stream of material; however, there may be physical restraints to mounting the camera to allow it to enter the bore hole with the nozzle. If the camera can be mounted with the nozzle, a separate bore hole for the camera is eliminated. If the camera has to be lowered down an adjacent bore hole, the view will not be as clear as if mounted at the nozzle. Offsetting the camera 3 or 4 feet from the production hole, on the other hand, may permit a better assessment of the amount of scattering occurring. The camera hole offset 3 feet perpendicular to the entry axis should permit viewing for both directions of throwing. A color TV camera may give a greater depth of perception than a black-and-white model, although a large-diameter bore hole, probably about 6 inches in diameter, would be required to permit the use of this type of camera.

Considering the capabilities of currently available bore hole video equipment, it is likely that a series of observation bore holes, drilled on approximately 25-foot centers, may be required to adequately observe the stowed material.

USE OF COMPRESSED AIR

Positive displacement blowers coupled to a power source currently represent the most common method of providing the air supply to the airlock and the pipeline.

Some of the newer feeding units are being designed to run on a supply of compressed air supplied by industrial air compressors quite common in the construction industry. These compressors should typically be capable of providing 1,200 to 1,800 cfm, at about 25 psi, when coupled to a 6-inch pipeline. The main advantage to using a compressor as the air source is that the specialized power source/blower assembly is replaced by a relatively common piece of construction equipment (i.e., the compressor).

The most probable benefit obtained by using a compressor, rather than a power source/blower, may be in project economics. It may be less expensive to stow a given amount of material using the compressed air equipment than using the power source/blower.

EFFECT OF MATERIAL TYPE ON SYSTEM WEAR

System wear is a constantly occurring phenomenon in pneumatic stowing operations. The conveyed material tends to erode moving parts it contacts in the feeder, and wears the conveying pipes and elbow through abrasion and impact. Remote pneumatic stowing will require the material to be transported at velocities higher than those normally used. The rate of system wear should be greater than that experienced in other applications.

Gradation

The grain size distribution of the material may affect its compacted in-situ density to a certain extent. Material placed at low unit weights will not provide as much roof support as a material of similar composition placed at a higher density. The grain size distribution of the stowing materials may be varied by crushing, screening, or other preparation methods. Various material gradations should be used in a demonstration remote stowing program so that the effect of material gradation on roof support may be determined.

Moisture Content

To achieve the highest degree of compaction, the proper moisture content must be maintained for some materials with a high degree of fines. Control of the moisture content often takes time, and results in an additional cost being incurred by the project. The direct effect of moisture content on compaction, and indirectly on roof support, should be determined by stowing a single material over a range of moisture contents in a demonstration project.

Cement

To improve the support capabilities of the stowed material, cement can be added as is accomplished when building road bases with coal refuse. The optimum cement content, which is the minimum cement content resulting in the desired amount of material support, would have to be determined by laboratory testing similar to that currently performed in the soil-cement industry. A test program should include these various mixtures to determine if cement will sufficiently improve the density and support characteristics of the stowed material. Pneumatically stowed fill, stabilized with cement, should be demonstrated.

The material cast furthest from the discharge nozzle will not be compacted to the degree required to provide adequate mine roof support; therefore, the addition of cement to the stowing material during initial filling may be warranted. The cement fill may be placed until the advancing pile face reaches the distance from the nozzle where adequate roof support may be obtained by compaction of the materials alone, without the need for the cement additive.

USE OF VIDEO EQUIPMENT FOR MONITORING STOWING OPERATIONS

General

The purpose of the bore hole video surveys for a remote pneumatic stowing project is to determine the mine conditions prior to mobilizing the injection equipment, to direct the fill material when stowing is in progress, and to observe that complete filling is taking place.

Preliminary Camera Work

Remote visual inspection of the proposed fill sites is required to determine the condition of the mine entries, location of obstructions such as roof falls, timbers, or abandoned mine cars, and in the absence of accurate mine maps, to choose the best locations for the stowing bore holes.

RECLAIMING ABANDONED MINE LANDS USING CONTROLLED RELEASE BACTERICIDES: A CASE STUDY

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Abstract

In cooperation with the Ohio Department of Natural Resources, one-half of a 5-acre abandoned coal refuse pile, reclaimed in July of 1984, was treated with a combination spray and controlled release bactericide pellets manufactured by The BFGoodrich Company under the ProMac® trademark. Both parts of the refuse pile received identical treatments of lime, fertilizer, seed mixtures and soil cover (6 to 8 inches in depth). The site has been periodically monitored for water quality, bacterial activity, and vegetation density and vigor.

Water quality data indicates a greater than 80% reduction in acidity, sulfates, iron, manganese, and aluminum for the ProMac treated side when compared to the untreated side. Tests for bacterial activity reveal that detrimental T. ferrooxidans are suppressed and the beneficial heterotroph population is over forty-times greater in the treated area. All of these factors contribute to the much healthier vegetation on the treated side that required no maintenance; the untreated part of the site has developed large barren areas from acid burnout.

INTRODUCTION

Bactericides have been proven to inhibit acid production in pyritic materials (Dugan 1975; Kleinmann and Erickson 1982; Sobek 1985; Shellhorn and Rastogi 1984; Sobek et al. 1985; Watzlaf 1986). They also provide other benefits. As the growth of detrimental acid-producing T. ferrooxidans is suppressed, the environment becomes more conducive to heterotrophic bacteria populations which are beneficial for revegetation (Sobek et al. 1985). Reductions in acid levels decrease the solubilization of aluminum, thereby reducing vegetation loss from aluminum toxicity (Sobek et al. 1985). A healthier vegetation in turn reduces erosion, downstream sedimentation problems, and reduces further pyritic oxidation by depriving the toxic material of oxygen and water. Healthier vegetation also produces humus and mycorrhizae which too promote the growth of heterotrophs and are inhibitory to T. ferrooxidans. Bactericides, if made to last long enough on a reclaimed site, help nature return the land to a productive non-polluting land form.

The BFGoodrich Company has developed a controlled release system to provide long-term control of acid generating bacteria (Sobek et al. 1985). The system results from the combination of expert reclamation services and ProMac

products. A spray is used for quick effective control of bacterial populations. The controlled release pellets come with different bactericide concentrations and release rates to maintain an effective bactericide level on the site for periods exceeding five years. The ProMac system maintains acid control and allows natural soil building activity to permanently provide a reclaimed site free from water polluting acid drainage.

RECLAMATION OF ABANDONED MINE LANDS

There are several specific objectives which the regulatory agencies endeavor to meet in the reclamation of abandoned mine lands. In order of priority, these are summarized below:

1. Protection of public health, safety, general welfare, and property from extreme danger of adverse effects of coal mining.
2. Protection of public health, safety, general welfare, and property from adverse effects of coal mining.
3. Restoration of land and water resources and the environment previously degraded by adverse effects of coal mining practices, including measures for the conservation and development of soil, water, woodland, fish and wildlife, recreation resources, and agricultural productivity.
4. Research and demonstration projects relating to the development of surface mining reclamation and water quality control program methods and techniques.

The use of bactericides certainly belongs under priority 3 and their use can be further tested under priority 4 if thought necessary.

Bactericides can be used in the reclamation of abandoned refuse piles, tipples and coal preparation plants, strip mine sites, and slurry impoundments. On spoil, they can be used with soil cover or without soil cover, provided the controlled release pellets are disced about 3 to 6 inches into the surface and appropriate plant nutrients are added to the spoil.

The use of bactericides is site-specific. The dosage rate and the correct combination of spray and controlled release pellets are determined from several factors, including:

Site material: pyrite content, net neutralization potential, sulfur forms, refuse, spoil, permeability.

Site topography: steepness of slopes, hollow fill, above ground.

Hydrology: surface water flow, groundwater sources and quality, expected run-off, proximity to bodies of water.

Microbial activity: T. ferrooxidans population.

Revegetation medium: spoil, paper mill sludge, quantity and quality of soil cover.

A typical reclamation is carried out in the following manner:

- The site is evaluated by a BFGoodrich ProMac Systems team.
- Samples of site material and water are brought back for testing in the laboratory.
- A report based on field observations, measurements, and laboratory data is presented to the client including a recommendation on the use of ProMac bactericide products.
- ProMac products are applied to the site after final grading under supervision of a BFGoodrich representative.
- Site monitoring services are provided if the client so desires.

Bactericides are not to be mistaken as substitutes for lime and soil. They are used with soil amendments and covered with soil; however, reclamation practices without using bactericides do not always resolve acid drainage or acid burnout, erosion and subsequent site maintenance problems. Their use provides additional insurance of success while reducing borrow areas, soil cover and lime.

Lime neutralizes acid after it is formed but allows it to continue forming. Heavy dosages of lime do not continue the neutralization process over long periods of time as the lime is quickly armored by metal salts (Hill 1974) and some researchers indicate that it accelerates acid production (Stiller 1985). With the use of bactericides, soil cover can be reduced to 1 foot, often poorer quality soil can be used, borrow areas and their deforestation can be reduced, lime requirements can be reduced, and future site maintenance can be minimized or eliminated.

ROUTE 43 TEST SITE

ProMac products are now in their third generation. The first generation products were applied to our oldest test site in the reclamation of an abandoned refuse pile called Route 43, near Steubenville, Ohio, under an agreement with the Ohio Department of Natural Resources, Division of Reclamation.

SITE DESCRIPTION

The Route 43 site is a 5-acre abandoned hollow-fill refuse pile about 30 years old. Figure 1 is a map of the site. All the drainage to and from the site is from rainfall and surface water. A seismic analysis was used to determine that there was no groundwater entering the refuse pile. A rain-fed stream ran along the bottom periphery of the site and pre-reclamation water quality is given in Table 1.

LABORATORY TESTING

Besides the water quality and site material testing, tests were run in the laboratory to determine microbial activity, site material acid-producing capability, and the effectiveness of bactericides on this material.

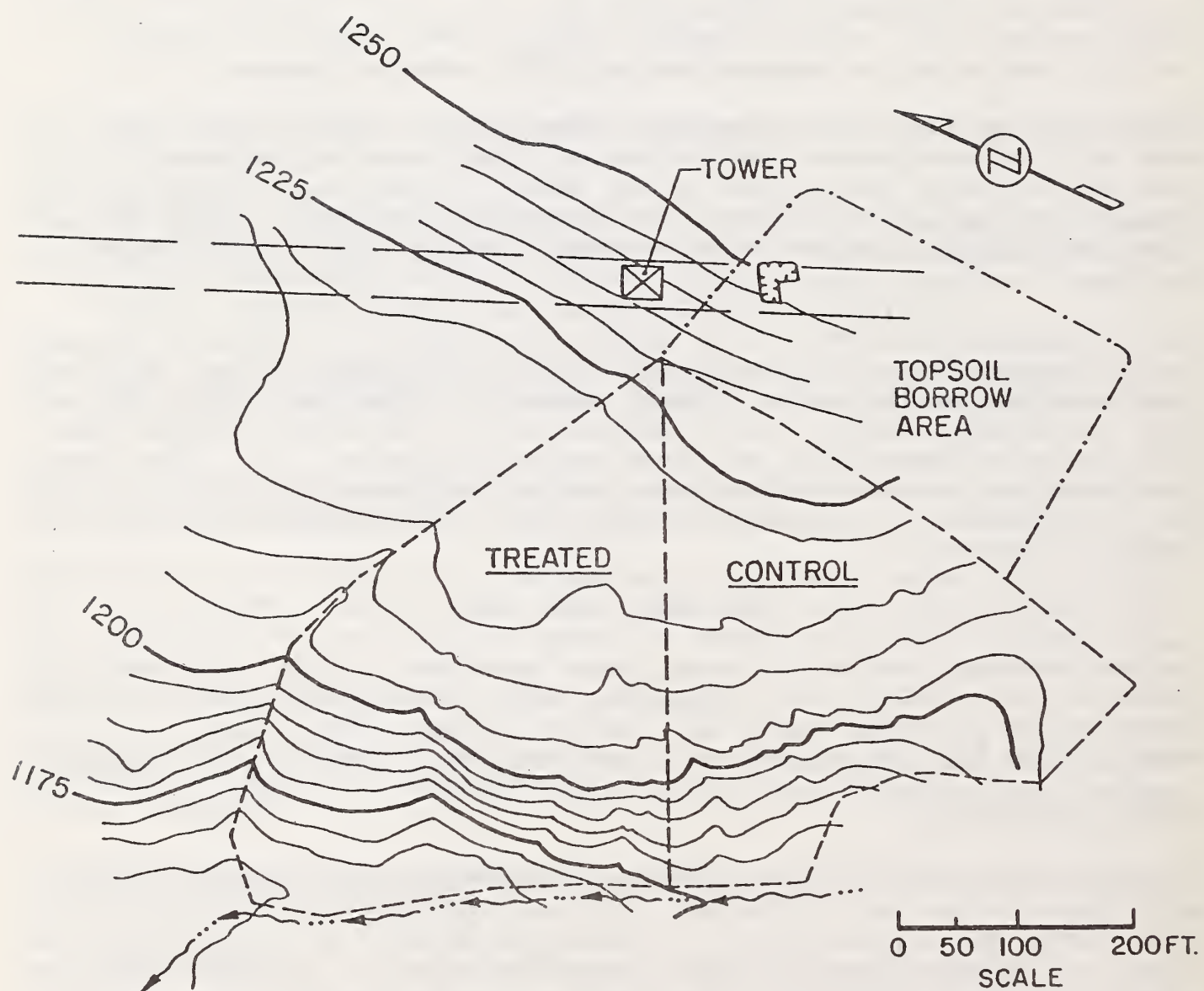


Figure 1. Route 43 test site.

Table 1. Pre-reclamation water quality.

	Seeps		Stream	
	One	Two	Entrance	Exit
Acidity, mg/l	1503	1391	0	1034
pH	2.7	2.4	6.4	2.7

Samples of the site material analyzed in our laboratory yielded the information shown in Table 2.

Table 2. Pre-reclamation site material analysis.

Pyritic sulfur	0.43%
Organic sulfur	0.78%
Sulfate sulfur	0.11%
Total sulfur	1.32%

The 9K media test on the site material gave strong positive indication of the presence of T. ferrooxidans by all samples producing a change in color to bright orange. A series of column tests and incubation tests were run to determine acid-production capacity and bactericide effectiveness. The testing methods have been previously described (Shellhorn and Rastogi 1984). The results are presented in Figure 2 which shows that the bactericides could reduce acid formation by 80-90%.

RECLAMATION

In order to test the effect of bactericides, it was decided to treat the left half of the site, but to reclaim the entire site identically at the same time using standard reclamation practices.

The entire site was first regraded to fill in erosion gullies which were at some places more than 10 feet deep, and to reduce the slopes to an acceptable level not to exceed 30 degrees to minimize future erosion. A hydroseeder was used to spray a mixture of ProMac bactericide spray, ProMac controlled release pellets and water over the regraded treated tract. Pans were employed to follow the spraying by putting a layer of soil 6 to 8 inches deep. The entire site was covered by soil obtained from a borrow area adjacent to the refuse pile. The site was next hydroseeded, limed, fertilized and mulched. The reclamation was completed in July 1984.

MONITORING

Data was collected from the site over a two-year period using several different techniques to provide different pieces of information.

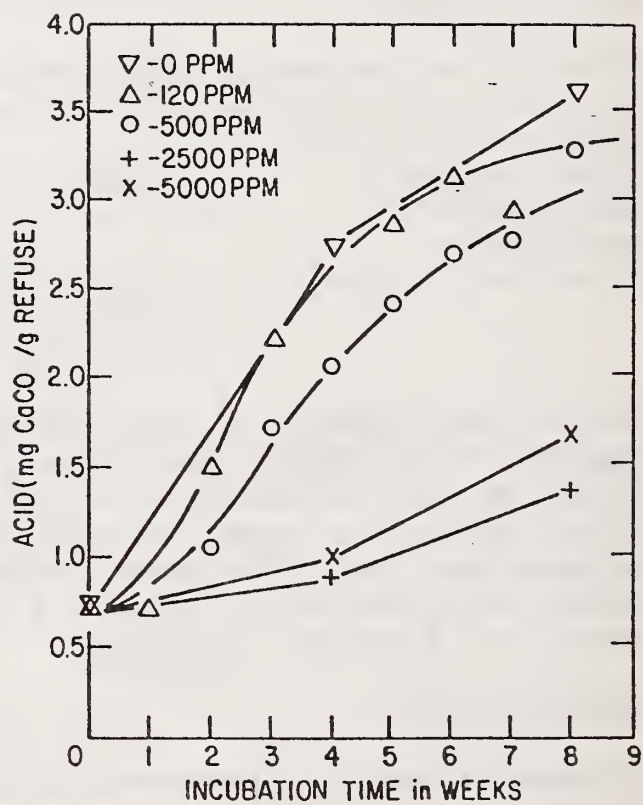
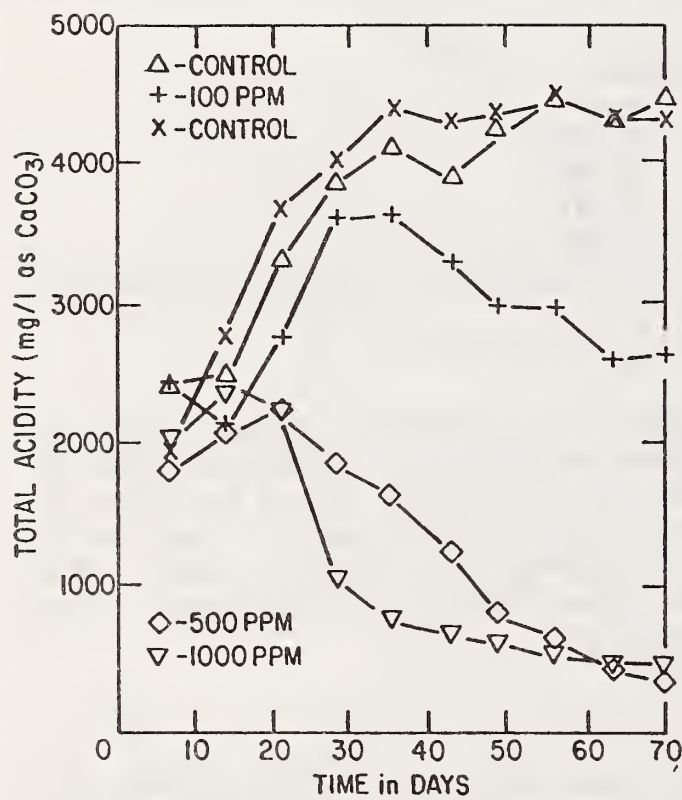


Figure 2. Effectiveness of bactericides in laboratory experiments.

Lysimeters

Eight lysimeters, four on each of the treated and untreated tracts, were used to determine refuse moisture at a depth of about 2 feet into the refuse. The lysimeters were sampled approximately once a month over the 2-year period by an independent laboratory. The results of this sampling is shown in Figure 3.

These results consistently show significant improvement in refuse moisture quality since reclamation because of bactericide treatment.

Core Samples

Core samples were taken once a year to determine acidity, iron, manganese, aluminum and sulfates, and to determine microbial activity. Coring procedures and analytical methods employed have been previously described (Sobek et al. 1985). Core samples further corroborated the lysimeter data. Table 3 shows the chemical analysis results from the two set of core samples.

Table 3. Core sample data showing percent improvement over untreated area.

	June 1985	June 1986
Acidity	43%	31%
Iron	294%	94%
Manganese	92%	52%
Aluminum	72%	143%

Microbial Activity

The microbial activity assessment was made from the core samples using MPN techniques. The results are shown in Figure 4. T. ferrooxidans population in the untreated tract was 170-times that in the treated tract and the beneficial heterotroph population was 30-times that on the untreated tract when checked in June 1985, one year after reclamation. In June 1986, while the T. ferrooxidans remained suppressed, the heterotrophs not only continued to show the large difference but have increased in their population (500-times) in the treated side.

Seeps and Stream

The site was monitored for seeps and stream water quality. In two years, no seeps have developed even though there are large damp burnout areas on the untreated side. The post-reclamation stream flows only during heavy rains and carries just rain water.

Vegetation

Vegetation was monitored visually and photographically using color and infra-red aerial photography. Throughout the two years, the treated tract has had denser, greener and healthier vegetation. The untreated tract rapidly developed growing burnout areas and has always had sparse, yellowish vegetation. Infra-red photographs show a much greater chlorophyll presence in plants on the treated side. The population of legumes on the treated side

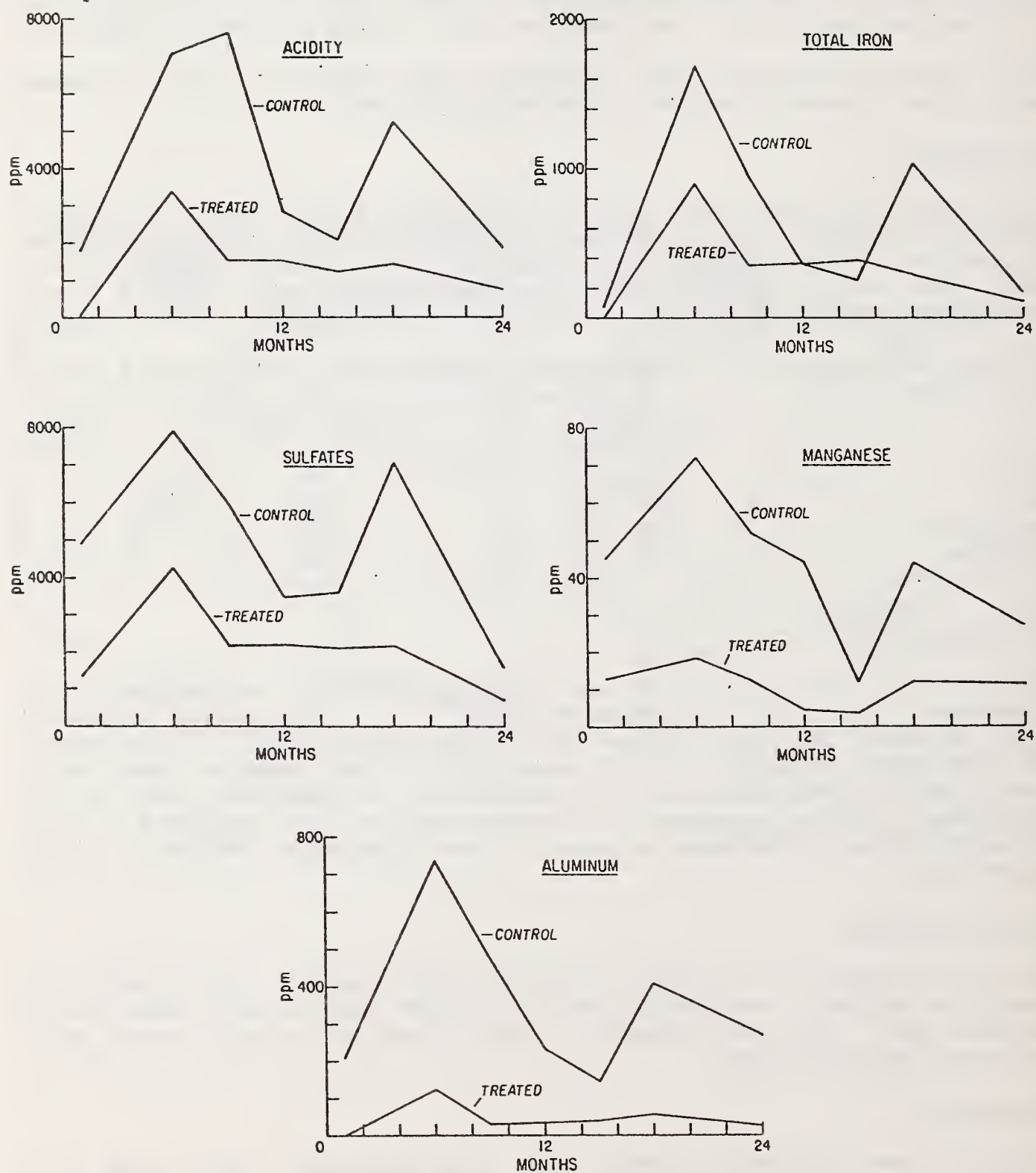


Figure 3. Refuse moisture quality results over 24 months from lysimeters.

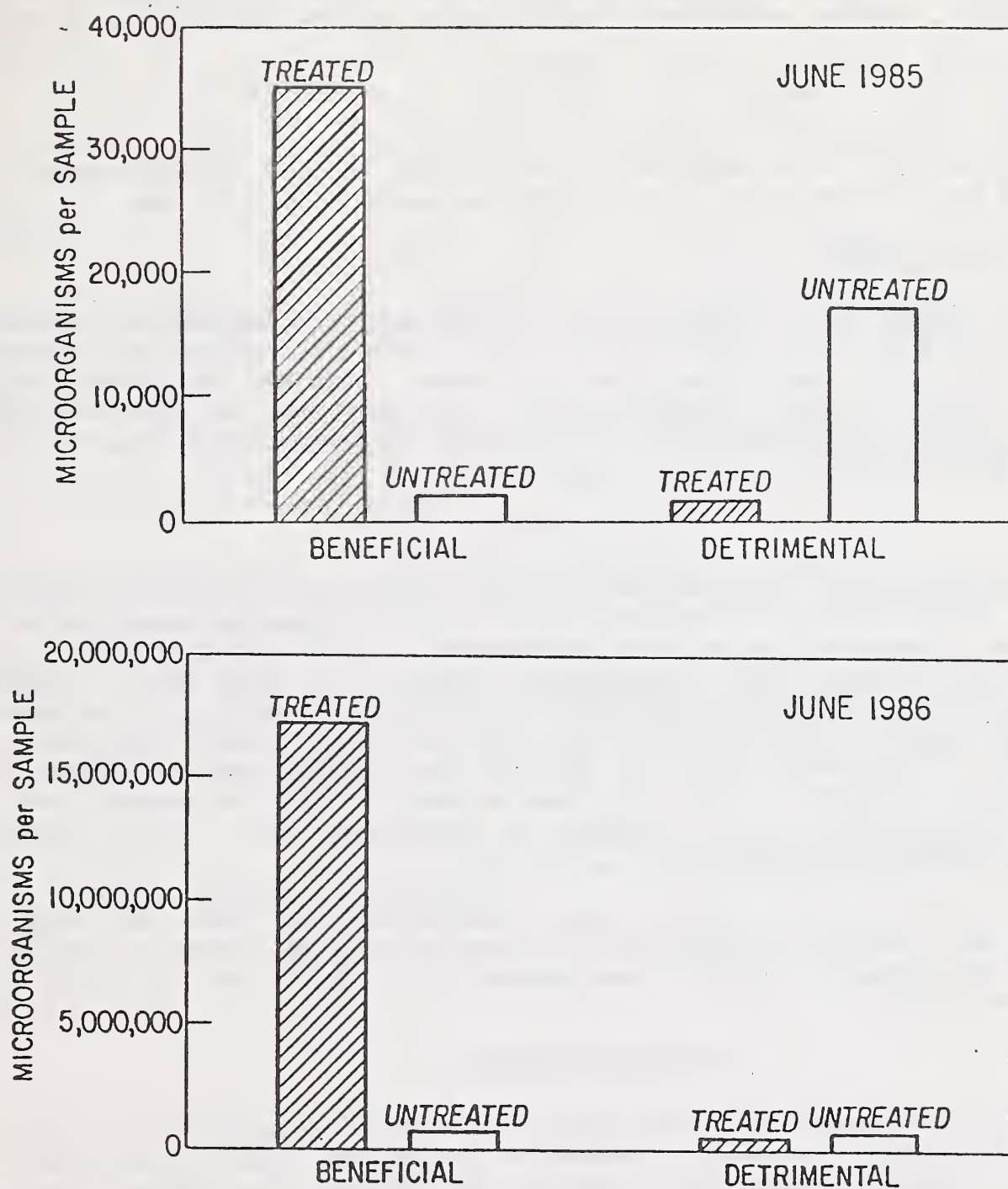


Figure 4. Microbial activity of beneficial heterotrophs and detrimental T. ferrooxidans over 24 months.

are a further indication of higher soil pH, lower acidity and aluminum, and a greater presence of beneficial heterotrophs. The treated side has developed a few burnout areas where coal and shale are readily seen at the surface, indicating patches of little or no soil cover. When only 6 to 8 inches of soil cover is applied, patches with little or no soil cover can be expected to be left behind.

Bactericides

No bactericides were ever detected in the stream or any off-site waters, showing that they do not create an environmental problem of their own.

Controlled Release Pellets

Pellets were removed once a year from the site to determine bactericide release rates and pellet life in the field environment. These first generation pellets appear to have a life span of less than two years. This was not unexpected based on laboratory testing of pellets, but it was extremely valuable data in developing the new third generation pellets which are expected to have a life span exceeding five years.

CONCLUSIONS

Two years of monitoring the Route 43 site has shown that controlled release bactericides can be extremely effective in acid control, promoting revegetation, and improving abandoned mine land aesthetically. The system required a considerable development effort spanning six years. On many sites it need cost no more than standard reclamation because of off-setting costs from reduced lime, topsoil cover, borrow area, and site maintenance. On others, its use may be justifiable simply to improve the environment and affected surface and groundwater, much in the same manner in which abandoned mine land reclamation is justified. Bactericides can also be used with topsoil substitutes such as paper mill sludge.

The system is site-specific and its use, effectiveness and costs will vary. However, it does provide an opportunity to resolve both the aesthetic problem and the water pollution problem simultaneously the first time, avoiding a hit-or-miss situation.

ACKNOWLEDGEMENTS

We would like to acknowledge with thanks the pioneering effort of the Ohio Department of Natural Resources, Division of Reclamation, and in particular, members of its staff: Messrs. Larry Mamone, Bob Baker, Dave Kieffer, Terry Van Offeren, Dave Buchanan, and Dave Stroh, for making this case study possible. We would also like to thank all the people at Jeffco Resources, Inc., who cooperated with us in every manner possible in the reclamation of this site.

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HAZARD REDUCTION TECHNIQUES USED FOR PIT SUBSIDENCE NEAR HANNA, WYOMING

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Abstract

Three different backfill techniques were used to reduce immediate hazards associated with pit subsidence over shallow coal mines near Hanna, Wyoming. The subsidence pits developed above abandoned mine workings in coal seams which dip between 15° and 25° and have less than 160 feet of cover. The hazardous subsidence pits were from 20- to 50-feet in diameter and from 20- to 30-feet-deep. All of the hazardous pits had very steep sides, indicating either recent caving at the ground surface or reactivation of older pits. Mining took place in the area of the subsidence pits about 75 years ago. At Site 1, backfilling with granular soils was used to eliminate the hazard at pits where backfill running was considered to be low. A grouted boulder wedge was used at the subsidence pit where backfill running was considered to be high. At Site 2, one of the subsidence pits broke to the ground surface along Standpipe Draw, causing runoff from this ephemeral stream to be diverted into the mine workings. Open boulder backfill was used in the area of Standpipe Draw to eliminate the hazard, but still allow runoff waters to enter the mine workings.

INTRODUCTION

Three different backfill techniques were used to reduce immediate hazards associated with pit subsidence over shallow, abandoned mine workings near Hanna, Wyoming. The backfilling was done as part of Wyoming Land Quality Division's Abandoned Mine Land Reclamation program in the Hanna area. The subsidence pits are located on open range land and, because of their depth and steep sides, the pits were considered to present an immediate hazard to humans and livestock. The subsidence pits were not in an urban area or where future land developments were anticipated; therefore, the goal of the backfill program was to eliminate the immediate hazard only. It was recognized that after backfilling, there would still remain a potential for the development of new subsidence pits within the project area.

The backfill operations discussed in this paper are part of the larger Project 7 reclamation efforts in the Hanna area being administered by the Wyoming Department of Environmental Quality, Land Quality Division, under their Abandoned Mine Land Reclamation Program. It is hoped that the experience gained during this backfilling project will be of use to others working in abandoned mine land reclamation and immediate hazard reduction.

PROJECT LOCATION AND GEOLOGIC SETTING

The hazardous subsidence pits were located about two miles east of the town of Hanna, Wyoming. The hazard reduction project involved two sites along the eastern limb of the Hanna syncline as shown in Figure 1. The coal mines in this area were in the Number 1 seam of the Paleocene-age Hanna Formation. The Hanna Formation is made up of interstratified brown to gray sandstone, shale, conglomerate and coal which were deposited in a fluvial environment. The formation is usually weakly cemented, and friable sandstones are common in the vicinity of the subsidence pits. The Hanna Number 1 coal seam varies from 4- to 27-feet-thick. The subsidence pits occur near the outcrop of the Number 1 seam in areas where the cover is less than 160-feet-thick. The No. 1 coal seam along the east limb of the Hanna Syncline dips between 15° and 25° toward the northwest. Several northwest trending small displacement faults offset the coal seams along the eastern and western limb of the syncline.

MINING METHODS

In 1889, the Union Pacific Coal Company began underground mining of coal near Hanna. These underground mines were operated until 1954. The drift method of mine layout was commonly used. The main haulage ways were driven along the dip of the coal seam, and secondary haulage entries were extended off the main haulage ways along the strike. Fifteen-foot-wide double and triple drift entries were used, and cross-cuts connected the haulage drifts on 50- to 200-foot centers. The height of the mine workings commonly ranged from 10 to 14 feet. Panel and pillar production areas were developed updip of the haulage drifts. The production panels typically were about 30-feet-wide and from 100- to 200-feet-long. At completion of first stage mining, 30-foot-wide pillars separated the work-out production panels. It was common practice during second stage mining to remove as much of the first stage pillars as practical. Mining took place in the area of the subsidence pits about 75 years ago.

SUBSIDENCE PIT SITE 1

Subsidence Pit Site 1 is located just to the south of the main line of the Union Pacific Railroad as shown in Figure 1. Four subsidence pits were present on Site 1 at the beginning of our field investigation in the spring of 1984. The general relationship of the pits to the mapped mine workings is shown in Figure 2.

DESCRIPTION OF THE HAZARD

When Site 1 was first visited in the early spring of 1984, all four subsidence pits were filled with snow and an assessment of the immediate hazards posed by the pits was difficult to make from the surface observations. After the snow melted, only Pits A and B were considered to present an immediate hazard. Pit A was about 20-feet in diameter, and Pit B was about 50-feet in diameter. The top of the caved material in the bottom of the pits ranged from 10 to 20 feet below the ground surface. The pit walls were nearly vertical to overhanging, indicating that caving to the ground surface had occurred relatively recently. During the field investigations, the floor of Pit B abruptly dropped an additional 10 feet. The other two pits at Site 1 appear older than Pits A and B. These pits were from 4- to 10-feet-deep and had

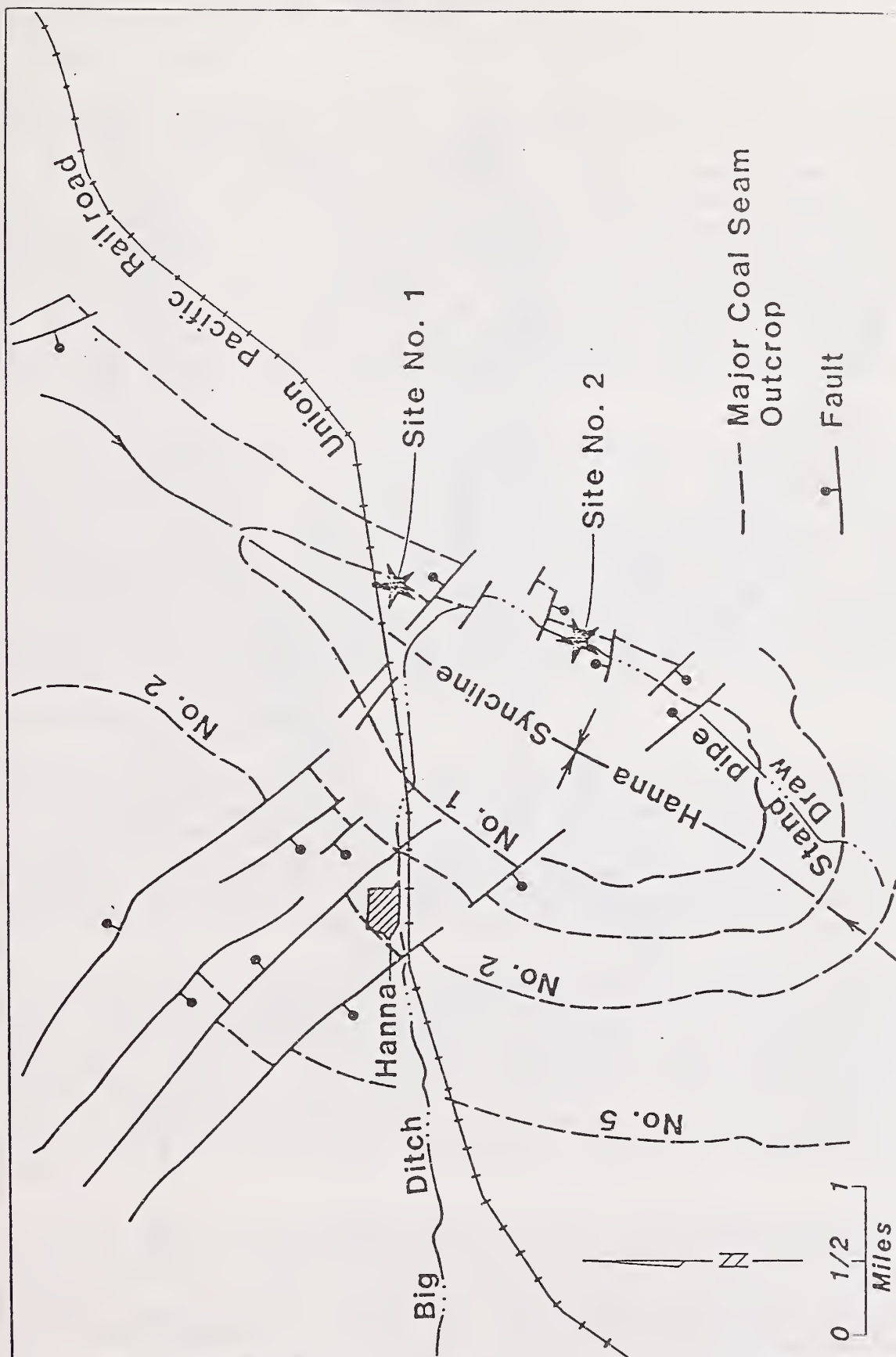


Figure 1.

SITE NO. 1

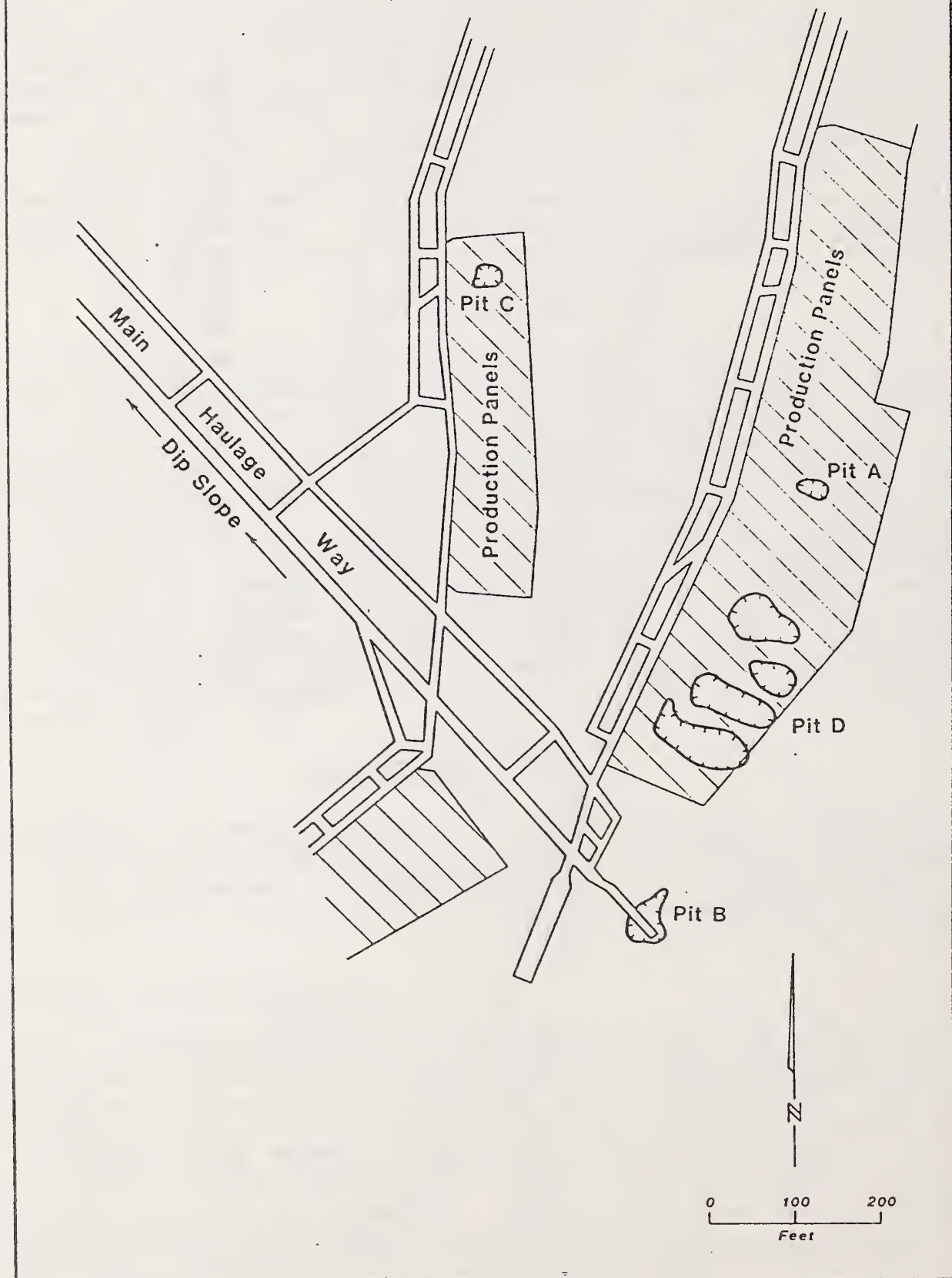


Figure 2.

relatively gentle sidewalls, indicating wall erosion subsequent to the initial breakthrough at the ground surface.

SITE INVESTIGATIONS

The subsidence conditions at Site 1 were investigated by reviewing the available mine maps, observing surface conditions and drilling several exploratory holes. The general subsurface conditions at Site 1 are shown in Figure 3, which is a cross-section through Pit B. The section parallels the main haulage way shown in Figure 2. The mine workings and coal seam dip from 15° to 25° toward the northwest. The cover between the mine workings and the ground surface is about 60 feet at Subsidence Pit A, 40 feet at Subsidence Pit B, 160 feet at Subsidence Pit C and 50 feet at Subsidence Pit D. The mine workings at Site 1 are below the water table. Subsidence Pit B is located near the southeast end of the main haulage way, whereas the other three pits are located in production panels.

Based on the mine geometry, it was inferred that there was a limited potential for large-scale running of the cave material and this material was considered relatively stable for the pits located in the production panels. This is not the case for Pit B, which is located on the main haulage way. Pit B presented a condition where periodic running of the caved material was likely. This inference was supported by the renewed subsidence in Pit B during the spring of 1984. In addition to the existing subsidence pit, field investigations also indicated that there is a potential for additional pit subsidence associated with other shallow undermined areas at Site 1.

METHOD OF HAZARD REDUCTION

After presenting the findings of the field investigation and reviewing several hazard reduction methods with the Wyoming Abandoned Mine Land Reclamation staff, it was decided that the most appropriate method of hazard reduction for the immediate hazards at Pits A and B was to backfill these two pits. It was not considered cost-effective to stabilize the entire site or to do work at Pits C and D which were not considered to present an immediate hazard.

Since it was inferred that there was a relatively low potential for large-scale running of the caved material in Subsidence Pit A, it was decided to fill the pit with a gradual backfill. The backfill used was scoria (baked shale) from a nearby source. The pit was filled by dumping from the ground surface, and the backfill was mounded to provide for settlement. The construction area was topsoiled and seeded after backfilling. Some settlement of the mounded backfill occurred in the fall of 1984, and additional backfill was planned in Pit A at that time.

Because of the potential for large-scale running of the caved material in Pit B, it was decided that a grouted boulder wedge would be used. The required excavation and finished construction of the wedge is shown in Figure 3. The caved material was excavated above the water table and the key for the wedge excavated into undisturbed bedrock. Three to 8-foot-diameter sandstone boulders were placed in the excavation and the voids between the boulders grouted. Grouting was done by placing a quick setting Portland cement grout through pipes installed prior to backfilling. A drain through the wedge was provided to prevent the development of perched groundwater. The drain

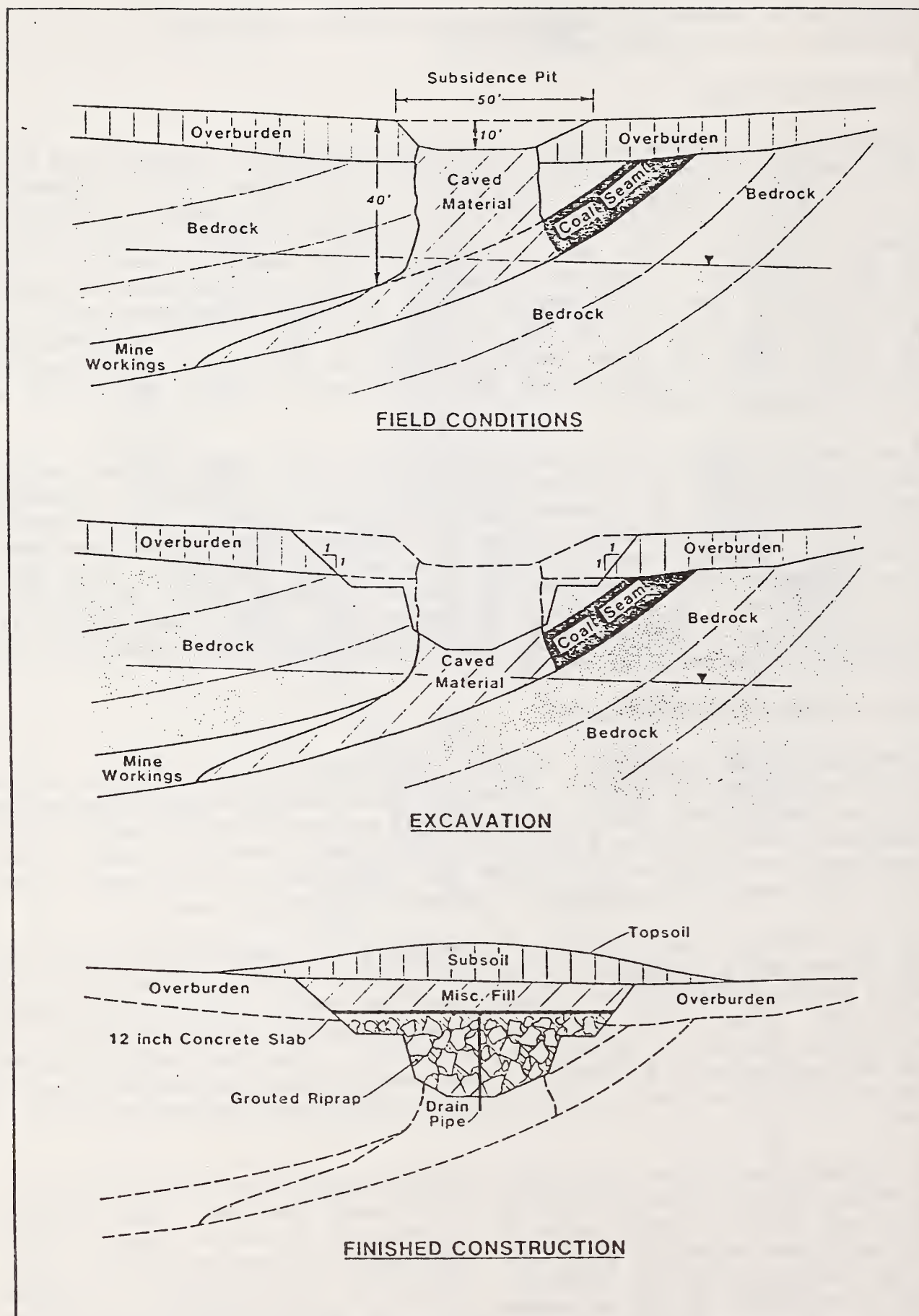


Figure 3.

consisted of a 12-inch concrete cap sloping to a drain pipe which was installed as the boulders were placed prior to grouting. A filter was placed over the pipe to prevent piping of the overlying soil backfill. After construction of the drain, the remainder of the excavation was backfilled with miscellaneous on-site soil, and subsoil and topsoil were mounded over the wedge. The construction area was then seeded.

SUBSIDENCE PIT SITE 2

Subsidence Pit Site 2 is located adjacent to Standpipe Draw about two miles south of Site 1, as shown in Figure 1. Standpipe Draw is a major ephemeral stream with a large drainage basin. Relatively high discharges on the order of 300 cfs occur during the spring snowmelt period; however, the stream channel is usually dry during other times of the year. Three subsidence pits were present at Site 2 at the beginning of the field investigation in the spring of 1984. The general relationships of the subsidence pits to Standpipe Draw and the mapped mine workings are shown in Figure 4.

DESCRIPTION OF THE HAZARD

Both Subsidence Pits A and B were designated as immediate hazards. These pits were about 20- to 30-feet-deep and had very steep side slopes. Pit C was not considered an immediate hazard. This pit was about 3-feet-deep and had relatively gentle side slopes. Caving in Pit A intersected the channel of Standpipe Draw and diverted the water flow into the mine workings. During the initial field investigations in the spring of 1984, the entire flow of Standpipe Draw was cascading into Pit A.

SITE INVESTIGATIONS

The subsidence conditions at Site 2 were investigated by reviewing the available mine maps, observing surface conditions and drilling several exploratory holes. The general subsurface conditions at Site 2 are shown on Figure 5, which is a cross-section through Pit A. The section parallels the main haulage way shown on Figure 4. Subsidence Pit A developed over the slope entry to the mine near the bedrock-overburden contact. Pits B and C were located at shallow vertical shafts which connected to the main haulage ways. The mine workings and the coal seam dip about 25° toward the northwest. The open haulage drifts downdip of the subsidence pits appeared to be in good condition and evidence of roof collapse was not observed. However, the potential for additional pit subsidence is recognized at Site 2.

METHODS OF HAZARD REDUCTION

After presenting the findings of the field investigation to the Wyoming Abandoned Mine Land Reclamation staff, it was decided to evaluate two general hazard abatement concepts. The first concept was to divert Standpipe Draw to the southeast around the shallow mine working and to provide stable seals and backfill the hazardous subsidence pits. The second general abatement concept was to reduce the immediate hazard by a design which would allow the water to continue to enter the mine workings. The second concept was adopted in the final design by construction of an infiltration gallery. The construction consisted of excavating the three subsidence pits down to the level of the first cross-cut drift as shown in Figures 4 and 5. Rail bar grills were constructed

SITE NO. 2

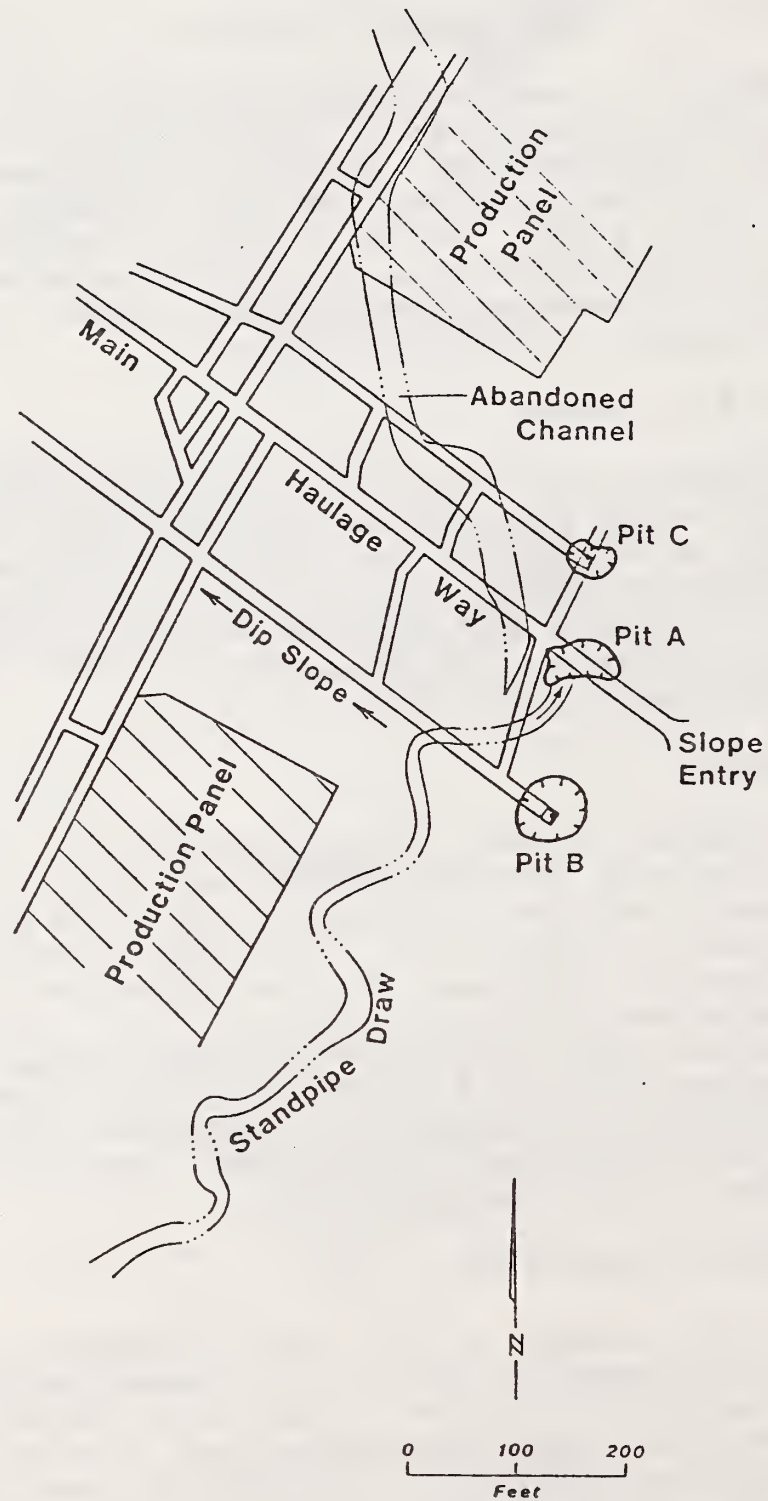


Figure 4.

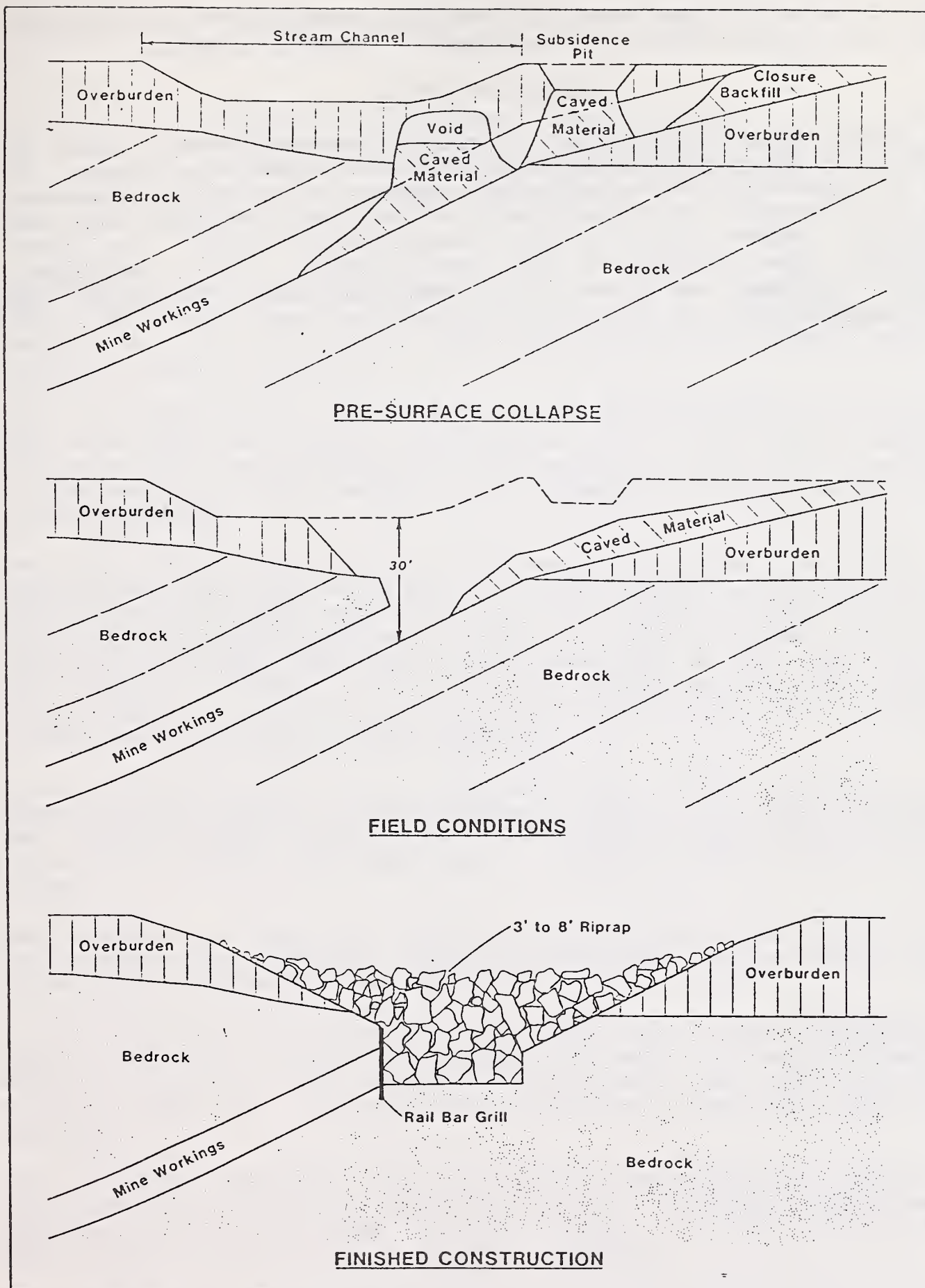


Figure 5.

where the excavation intersected the three main haulage drifts, and the excavation was backfilled with 3- to 8-foot-diameter sandstone boulders.

ACKNOWLEDGMENTS

The backfill operations were part of Project 7 reclamation efforts under the administration of the Wyoming Abandoned Mine Land Reclamation program. We wish to acknowledge the cooperation and assistance of the Wyoming Abandoned Mine Land Reclamation staff, particularly Mr. Gary Beach, Manager, Mine Land Reclamation Program, and Mr. Kurt Anselmi, Project Officer. The project consultant's team consisted of Chen and Associates, Inc.; Worthington, Lenhart, Carpenter and Johnson, Inc.; Range Inventory and Analysis; and Skelly and Loy, Inc.

THE BUFFALO ROCK RECLAMATION PROJECT

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Some claim that it is the largest land sculpture since Mt. Rushmore. Others point to it as an example of a unique way to restore an environmentally ravaged area. Still others cite it as an opportunity for the public to have a "hands on" experience with art.

"It" is the Buffalo Rock project--a 150-acre site 80 miles southwest of Chicago which now sports five earthen animal figures (up to 2,070 feet in length) where once there was only a barren eroded landscape; an area which previously stood only as an eerie remnant of coal mining activity completed and the land left devastated.

Now, nearly 45 years after mining was completed, the acreage has undergone a transformation that holds the promise of serving Illinois as a premiere landmark. That is, through rehabilitation work first begun in 1985, the Illinois Abandoned Mined Lands Reclamation Council has shaped the lifeless ridges and gulleys of the Buffalo Rock site into representations of five native Illinois animal species: a catfish, a frog, a turtle, a water strider, and a snake. Tourists should be able to view, and actually walk on, the forms beginning this fall, when the park is formally dedicated.

It is an undertaking that can be appreciated from several perspectives: it echoes the ancient ritual of mound-building; it points to the creative possibilities of public-private partnerships; and it testifies to the effectiveness of modern-day reclamation techniques that can rejuvenate lands scarred by coal mining.

The inspiration for Buffalo Rock, with its sprawling animal forms shaped in the soil, is drawn from prehistoric Indians who left their mark by similarly constructing huge artificial forms out of dirt.

It was a practice carried out over 3,000 years ago, as the inhabitants of central and eastern North America shaped the earth, not only into animal effigies, but also into cones and truncated pyramids. The custom prevailed for nearly 1,500 years, with the mounds functioning as burial sites and temple platforms.

Even by today's standards, the dimensions of the mounds are impressive. Without the aid of engineers, powered machinery, or any other sophisticated equipment, the ancient people nonetheless coaxed the earth into geometric forms as high as 150 feet and covering up to 20 acres.

For example, one of the more popular earthen structures was the temple mound. Often built in the flat-topped pyramid style, the temple mound was a

trademark of prehistoric people residing in the Mississippi Valley area and is believed to have provided platforms for temples that have since deteriorated.

A classic example of this form exists at Monk's Mound in Cahokia, Illinois. Rising some 100 feet in height, the earthen temple reigns as the largest existing soil sculpture in the northern hemisphere, and is considered the second largest earthwork in the world.

Another popular form executed by ancient inhabitants of the New World is tumuli, or burial mounds. Frequently these tumuli suggest the forms of men, animals, or cones.

This particular soil shaping was common in the Ohio Valley area. Effigy mounds fashioned after the shapes of men, reptiles, beasts, and birds are found almost exclusively in the Great Lakes region and surrounding areas. World famous among these is the Great Serpent Mound in Ohio. That sculpture, until the completion of the Buffalo Rock project, prevailed as the largest serpent sculpture in the world.

Centuries later--in 1985--an opportunity would present itself again to construct earthen sculptures, but this time at a seemingly unlikely site: an abandoned coal mine in north-central Illinois.

Specifically, the Buffalo Rock mine, actively worked as a surface mine from 1934 to 1942, would come to host five enormous effigies that echo the practices of primitive man. This site had undergone massive uprooting in pursuit of a meager 1½ foot seam of coal.

In the course of harvesting the coal, there was cast aside acre after acre of overburden--the soil and rock overlying the coal deposits. On average, the ridges and piles of useless material approached 25 feet in height.

At the time mining activity concluded at Buffalo Rock (1942), there were no efforts to restore the land; no regulations were yet in place to require coal operators to reclaim their sites. Consequently, the ridges of overburden (called spoil), were left exposed and became so highly acidic that even 40 years later the site continued to reject vegetation.

Other environmental problems plagued the site as well. For example, the irregular topography of the site allowed surface water to collect sediments and acidify. In turn, this toxic water and sediment washed into the Illinois River and a nearby lake, contaminating both. Adjoining ditches routinely became clogged with runoff from the mine as well, often resulting in localized flooding. The area was desperately in need of restoration work.

Fortunately, the resources eventually were developed to give the site the attention it needed. In 1975, the Illinois Abandoned Mined Lands Reclamation Council was established to address, in general, problems at abandoned coal mines--those sites that have no responsibility for reclamation associated with them.

Significantly boosting this effort was a federal law passed two years later. Under the 1977 Surface Mining Control and Reclamation Act, active coal companies contribute to a federal program that is then used to fund reclamation at

abandoned mines. These fees are assessed at a rate of 35¢ per ton for surface-mined coal and 15¢ per ton for deep-mined coal.

But in Illinois, many sites were vying for reclamation funding. In order to determine which mines were most in need of rehabilitation work, the Council updated the state's inventory of abandoned mines in 1980. This update identified 700 sites that were classified as "high priority" based on the extent of the safety and environmental problems that they posed.

Among the top contenders for restoration identified by the 1980 inventory was the Buffalo Rock mine. In fact, the extreme conditions at the site made it one of the most environmentally unstable areas in the state.

While devising a strategy to clean up the Buffalo Rock mine, an opportunity presented itself to the Reclamation Council to do creative reclamation work by establishing a public-private partnership. A private organization, the Ottawa Silica Company Foundation, commissioned for the state the noted artist Michael Hiezer who developed plans for land sculpting at the site. This work entitled "Effigy Tumuli Sculpture", was designed in conjunction with the reclamation plan. In addition, the Ottawa Silica Company, owner of the land, donated it to the state with the goal that it would eventually be available for public recreational use.

The first phase of the Council's work is only a year old. Completed in August of 1985, the massive first-stage effort included the limestone treatment of 6.3 million gallons of acid water and construction of the water strider effigy (14 feet high, 685 feet long). Under phase two of the project, four other effigies were built: a frog (17.5 feet high, 340 feet long), a catfish (18 feet high, 770 feet long), a turtle (650 feet long), and a snake (7 feet high, 2070 feet long). Standard reclamation work was performed on adjoining acreage as well.

Together, both phases of construction required the excavation of 462,506 cubic yards of spoil material. In many respects, traditional reclamation techniques were employed. That is, once the materials had been graded in accordance with the artist's design, limestone was incorporated into the soil. Straw mulch was then applied to protect the graded areas from erosion and to retain moisture for better seed germination. Finally, the area was seeded and the effigies only were covered with excelsior blanket to further protect the slopes from erosion.

The total cost of the reclamation work was approximately \$1 million. And at only two-thirds the cost of more traditional surface mine reclamation work, the Buffalo Rock price tag is favorable indeed: the effigy site cost \$7,000 per acre, compared to the average cost of surface mine reclamation in Illinois which is \$10,000 per acre.

In many respects, Buffalo Rock lent itself especially well to this unique reclamation approach. For example, the very nature of the topography of Buffalo Rock--a result of the surface mining activities--already suggested the desired configurations, so that the need for special earth-moving was minimal. In addition, the site is adjacent to the Buffalo Rock State Park so that it will have a ready source of visitors. Although, of course, the effigies are expected to become a landmark in their own right. Finally, the site offers various vantage points from which to view the land sculptures. River traffic on the

Illinois River, which runs adjacent to the site, will be able to view some of the effigies, while footpaths will enable the public to walk directly onto the sculptures. The peaks of the effigies will also offer vantage points from which portions of the site may be viewed.

Actual public viewing will be permitted after mid-October when the site will be formally dedicated. At that time, Buffalo Rock is expected to join other Illinois landmarks, serving as a tribute to land sculpting techniques borrowed from ancient man, to be enjoyed now by modern man.

AERIAL TREATMENT ACTIVITIES FOR REVEGETATING DISTURBED LANDS

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Abstract

This paper addresses the Tennessee Valley Authority's (TVA) experiences in aerial (helicopter/spreader bucket) seeding and fertilization of disturbed lands. Treated sites include both coal and non-coal mineral surface mined lands, as well as other land disturbances throughout the seven-state area of the Tennessee Valley. Since 1982 nearly 4,200 acres have been treated by TVA through this approach. Ground-support needs, loading techniques, application methodology, and costs are discussed. TVA's on-the-ground experiences indicate that aerial treatment activities are a cost-effective and environmentally sound revegetation practice for disturbed lands. However, this method of revegetation is often overlooked. As the states start treating environmental problem (priority 3) abandoned coal mine lands, as defined by Title IV of the Surface Mining Control and Reclamation Act of 1977, they may want to consider aerial treatment for selected mine sites.

INTRODUCTION

Reestablishment of vegetation is the most effective means of stabilizing disturbed lands. The vegetation also provides long-term watershed protection benefits. Grasses and legumes are considered the best plant materials for short-term soil stabilization, while trees and shrubs offer a long-term maintenance free protective canopy (USEPA 1976).

Seeding of grasses and legumes, along with certain tree seed is accomplished by either broadcasting or drilling. The most common methods of dry broadcast seeding are by hand-operated cyclone seeders or by seeders mounted on a tractor or other implement. Seed can also be dry broadcast by blowers that are rear-mounted on a truck or spread through a conventional lime spreading truck. A popular method for wet broadcast seeding of steep slopes in Appalachia is known as hydroseeding. Drilling the seed is popular in dry regions because the seed is planted in the spoil offering improved germination and growth.

Whether broadcasting the seed with a farm tractor and implements, rear-mounted blower, hydroseeding, or drilling, a major limiting factor to these methods is site accessibility. For example, truck mounted equipment requires good access roads and tractor cyclone seeding can generally only be conducted on gently sloping, ungullied subsites within the treatment boundary. The use

of drills is even more limited to treatment areas that are relatively free of stones and accessible to conventional type farm machinery.

To overcome the terrain and accessibility problems associated with conventional seeding methods and to explore a potentially more cost-effective approach to establishing vegetation on disturbed lands, TVA in 1982 began evaluating aerial seeding and fertilization by helicopter (TVA 1984). Early results and costs were favorable, and the technique has since become a common practice in TVA's Land Reclamation Program. To date, TVA has aerially treated nearly 4,200 acres of disturbed lands throughout the seven-state area of the Tennessee Valley (Muncy and Bollinger 1984). The treated sites include coal and non-coal mineral surface-mined lands, coal slurry ponds, construction sites, coal-fired steam plant ash ponds, and forest lands destroyed by wildfire. The purpose of this paper is to report on these experiences in aerial seeding and fertilization of disturbed lands.

THE AERIAL TECHNIQUE

Aerial seeding and fertilization is not a new practice in revegetating disturbed lands. However, it is often an overlooked method. It is simply another form of broadcast seeding. Both fixed-wing aircraft and helicopters can be tailored for seeding. However, a helicopter generally is better at reaching out-of-the-way sites, does not require a landing strip, and its payload capabilities are more flexible. A versatile helicopter team can operate from remote jobsites and can generally work out of the site being treated. This decreases ferry time between loads and permits constant communications between the ground team and pilot.

EQUIPMENT AND GROUND SUPPORT

TVA's aerial seeding and fertilization team presently involves small (Bell 47 turbine conversion) and medium (Bell Huey 204-B) utility helicopters combined with aerial spreaders. Ground support includes a supervisor, mechanic, fuel tanker truck and operator, material trucks, and an experienced crew.

The aerial spreader or "sling bucket" is attached to a helicopter by a cable harness system which includes a gate control mechanism operated by the pilot. Aerial spreaders are designed to apply high volumes of dry material such as seed and fertilizer. The spreaders are gasoline-driven and each holds 40 cubic feet of material (about a ton of fertilizer). Inside the spreader, a hydraulic cylinder raises the gate to a predetermined height to regulate flow.

MATERIALS APPLICATION

Dry materials that the spreader can dispense are grass and legume seed, certain tree seed, granular fertilizer, and pelletized agricultural lime. Dispersal rates of up to 2,200 pounds per minute with an effective swath width of 120 feet are possible. However, the flow rate can be precisely calibrated for various application rates down to only a few pounds per acre. This control combined with a constant helicopter speed provides uniform coverage. Also, because of the helicopter's versatility and control, hilly terrain can be flown on the contour. Large treatment boundaries are sometimes flown in a criss-cross manner to further assure uniform distribution of materials.

If a seedbed is not prepared across the treatment site, the preferred time period to do aerial seeding is in late winter to take advantage of loosened soil resulting from freezing and thawing periods. However, certain soil types can be aurally seeded with good results without site preparation. Seedbed preparation needs should be determined on a site-specific basis.

Other possible uses of the aerial approach are in top dressing existing vegetation with fertilizer and in applying pelletized agricultural lime. Aerial application of pelletized lime should only be considered for extremely critical and inaccessible sites, because of the high cost of this material. Typical pulverized agricultural lime or any talc type material will not feed through a standard aerial spreader. Aerial application of typical agricultural lime is presently only possible through a dump bucket system. There are types of rock lime that will feed through the spreader, but most have a very poor neutralization ability. The rock lime generally becomes coated over and will not breakdown rapidly. Thus, it quickly loses acid neutralization capability.

There are guidelines that should be followed when selecting the actual materials to be spread. Specifically, high analysis fertilizers should always be used. Straight high analysis fertilizer can be combined to achieve the precise desired nutrient level. Under this approach, less bulk material is required, and there are no unneeded nutrients and there is less filler material involved than commonly found in mixed low analysis fertilizers. Thus, costs are reduced for transportation, handling, and application.

When treatment plans call for a seed mixture of different grasses and legumes to be applied, the mixture should be thoroughly blended or premixed at the source of supply and placed in 50-lb bags. Also, most seed companies can inoculate the seed of herbaceous legumes with the appropriate strain of rhizobia in the blending process.

To aid in loading and application, seed and fertilizer can be dry mixed together. However, certain fertilizers such as a high analysis blend of urea (46-0-0) and diammonium phosphate (18-46-0) can easily draw moisture from the air and go into solution. This high concentration of salts going into solution could quickly damage the seed (USFS 1974).

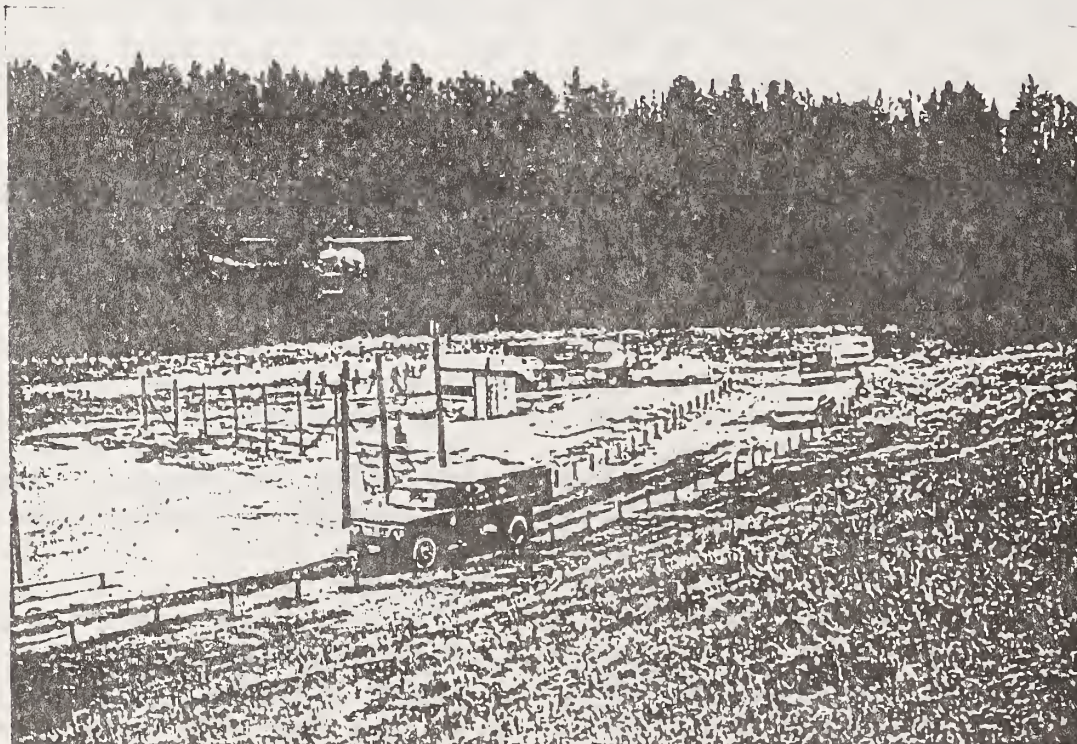
LOADING

The aerial spreader is generally bulk-loaded with dry material from a bin chute-type loader mounted on the bed of a pickup or flatbed truck. The helicopter hovers above while the spreader is being loaded. The bin itself is loaded by another truck with an auger, front-end loader, or by hand while the helicopter is away spreading material. The bin loader system is an effective approach, but TVA's experiences have involved different types of loading methods that have included both bulk and bagged materials (Figures 1-A and 1-B). To keep the aerial operation efficient, the spreader loading time must be kept to a minimum.

In bulk fertilizer and pelletized lime loading operations, TVA has loaded the spreader directly from the rear of a 25-ton frame dump trailer, trucks with auger extensions, and trucks with conveyor extensions. On certain jobs bagged fertilizer has been loaded by hand. The fastest bulk loading system of those tried by TVA is by rear dumping through the grain door of a frame



A. Loading bulk pelletized lime into an aerial spreader.



B. Hand loading bagged seed and fertilizer into an aerial spreader.

Figure 1. Methods of loading an aerial spreader combined with small and medium utility helicopters.

trailer. This method takes about 20 seconds to load 2,000 lbs and requires no second handling of the material. Seed is generally loaded by hand dumping 50-lb bags for 1,000-lb loads. Spreader seed loading time requires about 45 seconds.

The method of loading and the type of helicopter selected for a particular job should be based upon the quantity of materials to be applied, along with the size and proximity of treatment sites. For example, where one large contiguous boundary is to be treated, bulk methods prove most effective. However, where there are numerous small sites scattered over a larger geographical area it may be more advantageous to hand-load both bagged seed and fertilizer for transportation and logistic reasons.

EXAMPLES OF PROJECTS AND ASSOCIATED COSTS

LANDS DENUDED BY COPPER SMELTING

TVA has been cooperating with Tennessee Chemical Company in revegetating lands denuded by a century of copper smelting activities in the Copper Basin area of Polk County, Tennessee, and Fannin County, Georgia (Muncy 1986). Recent work in 1985-1986 has concentrated on improving the growth and vigor of chlorotic loblolly pine (*Pinus taeda* L.) stands and establishing ground cover in these young plantations. The sites are inaccessible to conventional ground equipment and aerial treatment methods were judged the only feasible alternative.

Ground cover establishment consisted of spreading 500 lb/acre of high analysis (12-24-24) fertilizer and 85 lb/acre of an acid-tolerant seed mixture of grasses and legumes, along with black locust (*Robinia pseudoacacia* L.) seed. Most treatment sites were within a 1½ mile radius of the loading zones.

The fertilizer was bulk-transported to the jobsites in 25-ton frame dump trailers. Fertilizer loading was accomplished by rear dumping through the grain door of the trailer into the spreader. Seed loading involved hand dumping 50-lb bags. Average direct cost was \$207/acre (Table 1).

Table 1. Aerial treatment breakdown for ground cover establishment on denuded Copper Basin lands in southeast Tennessee and north Georgia.*

	Quantity	Direct Costs	Cost Percent
Seed mixture	38.7 tons	\$91,015	48
Fertilizer	230.0 tons	49,425	26
Flight time** (Bell Huey 204-B)	50.2 hours	32,630	17
Stand by (mechanic, fuel truck and operator)	11.5 days	8,357	4
Ground crew and vehicles	10.5 days	10,150	4
TOTAL	925.0 acres	\$191,577	100
COST/ACRE		\$207	

* Materials were spread during three separate treatment periods: 3/24/85 to 4/2/85; 9/9/85 to 9/11/85; and 3/23/86 to 3/26/86.

** Includes 5.3 hours of ferry time to and from the jobsites.

A supplemental application of seed and fertilizer was conducted on selected sites totaling 359 acres. Per acre treatment involved spreading 280 lb of fertilizer and 22 lb of seed. Direct cost for this work averaged \$106/acre (Table 2).

Table 2. Aerial treatment breakdown for supplemental application on denuded Copper Basin Lands in southeast Tennessee.*

	Quantity	Direct Costs	Cost Percent
Seed mixture	4.0 tons	\$18,490	49
Fertilizer	50.0 tons	10,343	27
Flight time** (Bell Huey 204-B)	9.0 hours	5,850	15
Stand by (mechanic, fuel truck and operator)	2.0 days	1,543	4
Ground crew and vehicles	2.0 days	1,900	5
TOTAL	359.0 acres	\$38,126	100
COST/ACRE		\$106	

* Materials were spread during one treatment period--3/27/86 to 3/28/86.

** Includes 1.8 hours of ferry time to and from the jobsites.

NATIONAL FOREST LANDS DESTROYED BY WILDFIRE

A four-day forest fire in the spring of 1985 in the Caldwell County, North Carolina portion of the Pisgah National Forest burned about 2,200 acres. The vegetation was severely charred on 471 acres. In an emergency effort to protect the adjacent high quality mountain trout streams from sedimentation, the U.S. Forest Service (USFS) requested TVA's help in aerially seeding and fertilizing the barren lands (TVA 1985). The USFS provided the materials and reimbursed TVA for its costs.

The project consisted of spreading 100,700 lb of high analysis (33.5-0-0) fertilizer and 20,000 lb of seed over 471 acres. The fertilizer was loaded into the aerial spreader by rear dumping bulk material through the grain door of a 25-ton frame trailer. The seed was loaded into the spreader by hand dumping 50-lb bags.

Nine different mountainous sites were treated. The largest boundary was 243 acres and the smallest was 8 acres. The sites were within a 3.5 mile radius of the loading zone. The application cost for this job averaged \$79/acre (Table 3).

ABANDONED MICA, FELDSPAR AND KAOLIN SURFACE MINE LANDS

Through cooperative efforts with local, state and Federal agencies, the mining industry, and landowners 590 acres of abandoned non-coal mineral minesites in Avery, Mitchell, and Yancey Counties, North Carolina were successfully reclaimed from 1980-1985 (Muncy 1985a). The 590 acres are spread across the three mountainous counties and involved 103 different minesites.

Aerial seeding and fertilization for ground cover establishment was conducted at 71 of these sites totaling 348 acres. The treatment per acre involved spreading 85 lb of seed and 400 lb of a blend of high analysis (19-19-19 and

0-46-0) fertilizers (Table 4). A small utility helicopter (Bell 47 Soloy) combined with bagged material and hand loading was selected for this job, since the individual treatment sites averaged only about 5 acres and were widely scattered. This operation required using six different loading areas in the center of each treatment sector. Each treatment sector covered about 10 square miles.

Table 3. Aerial treatment breakdown for ground cover establishment on Pisgah National Forest lands destroyed by wildfire in western North Carolina.*

	Quantity	Direct Costs	Cost Percent
Seed mixture	10.0 tons	\$ 9,300	25
Fertilizer	50.4 tons	10,584	29
Flight time** (Bell Huey 204-B)	19.6 hours	12,740	34
Stand by (mechanic, fuel truck and operator)	3.0 days	2,143	6
Ground crew and vehicles	2.5 days	2,269	6
TOTAL	471.0 acres	\$37,036	100
COST/ACRE		\$79	

* Materials were spread during one treatment period: 5/13/85 to 5/15/85.

** Includes 5.6 hours of ferry time to and from the jobsite.

Table 4. Aerial treatment breakdown for ground cover establishment on abandoned non-coal mineral mine lands in western North Carolina.*

	Quantity	Direct Costs	Cost Percent
Seed mixture	14.8 tons	\$30,376	39
Fertilizer	69.5 tons	15,429	20
Flight time** (Bell Huey 204-B)	40.6 hours	13,195	17
Stand by (mechanic, fuel truck and operator)	9.5 days	6,786	9
Ground crew*** and vehicles	10.5 days	12,181	15
TOTAL	348.0 acres	\$77,967	100
COST/ACRE		\$224	

* Materials were spread during two separate treatments: 4/9/84 to 4/20/84; and 8/13/84 to 8/14/84.

** Includes 4.4 hours of ferry time to and from the jobsite.

*** Includes crew per diem costs.

Over the five-year period the 348 aerially seeded acres, along with another 242 ground seeded acres also received two separate supplemental aerial top dressings of high analysis fertilizer at the rate of 250 lb/acre. Direct costs for each application averaged about \$65/acre.

ABANDONED COAL SURFACE MINE LANDS

From 1982 to 1984 TVA reclaimed 535 acres of abandoned coal mine lands that were adversely impacting the water quality in TVA's Upper Bear Creek Reservoir in Franklin County, Alabama (TVA 1981). In addition to TVA's

work, the U.S. Office of Surface Mining and the State of Alabama reclaimed other critical abandoned mine lands eligible for treatment under Title IV of the Surface Mining Control and Reclamation Act of 1977.

Under TVA reclamation activities, 315 acres were aerially seeded and fertilized by the sling bucket approach. The 315 acres comprise five different mine sites. The treatment sites were within a mile radius of the loading zone. Application rates per acre were 111 lb of seed and 445 lb of a blend of high analysis (39-0-0 and 0-46-0) fertilizers. The fertilizer was bulk transported by trucks to the jobsites and off loaded into the aerial spreader by a portable conveyor attached to the fertilizer truck. Seed loading was accomplished by hand dumping 50-lb bags. This project averaged \$173 per acre (Table 5).

Table 5. Aerial treatment breakdown for ground cover establishment on abandoned coal mine lands in northwest Alabama.*

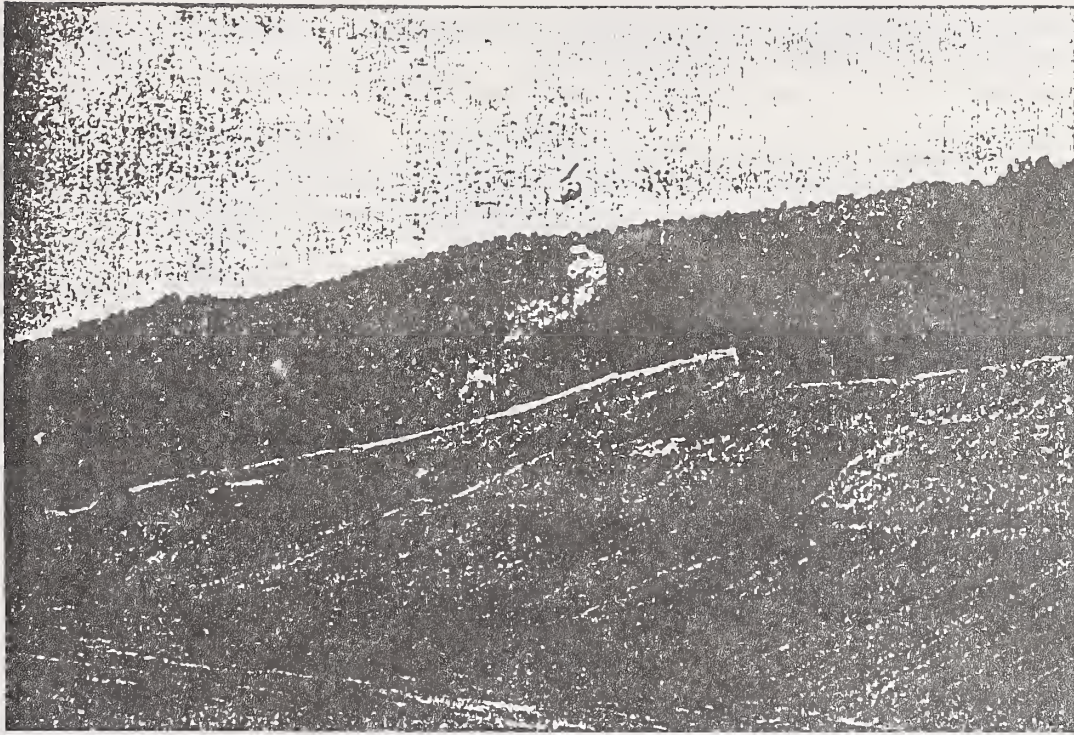
	Quantity	Direct Costs	Cost Percent
Seed mixture	17.5 tons	\$15,500	29
Fertilizer	70.0 tons	19,775	36
Flight time (Bell Huey 204-B)	17.1 hours	11,115	21
Stand by (mechanic, fuel truck and operator)	4.0 days	2,858	5
Ground crew and vehicles	5.0 days	5,064	9
TOTAL	315.0 acres	\$54,312	100
COST/ACRE		\$173	

* Materials were spread during one treatment period: 8/28/84 to 8/31/84.

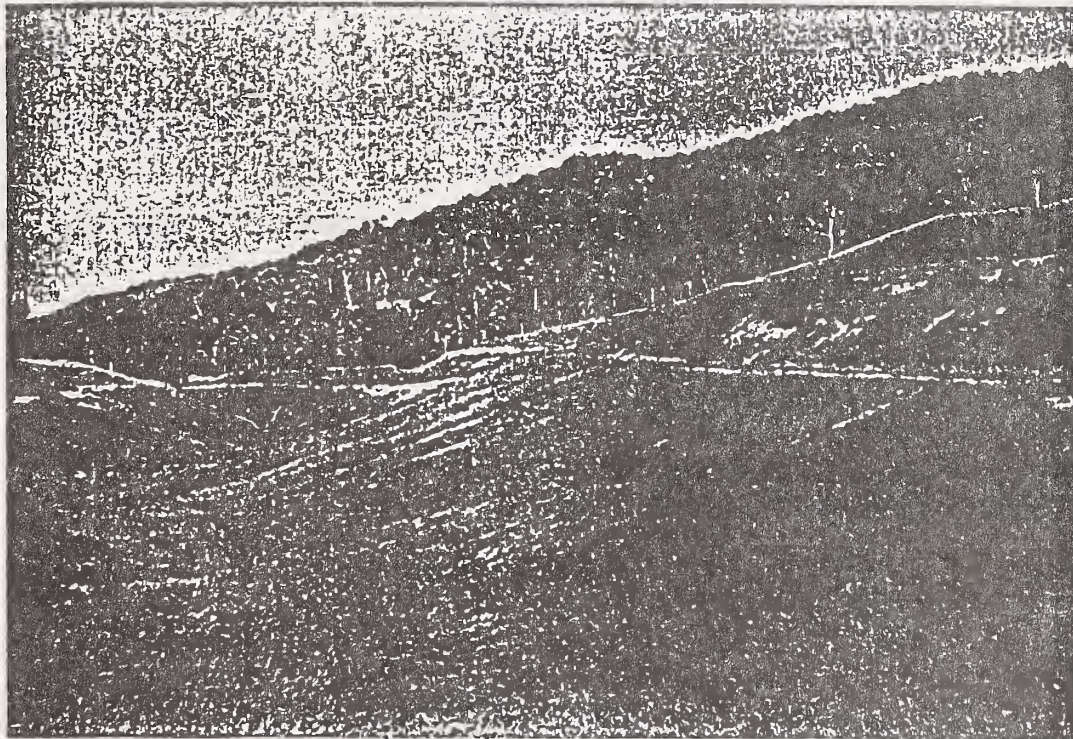
ABANDONED MANGANESE SURFACE MINE LANDS

During 1985 and 1986 TVA reclaimed 209 acres of abandoned manganese mine lands at 36 different sites in Smyth County, Virginia, and Johnson County, Tennessee (Muncy 1985b). Part of the lands (99 acres) in Virginia are located on the Jefferson National Forest which is managed by the USFS. In 1985 TVA, in cooperation with the USFS and other private landowners, reclaimed 135 acres at 21 different sites.

Part of the treatment activities on the 135 acres in southwest Virginia consisted of aerially spreading pelletized agricultural lime, a blend of high analysis (18-46-0, 0-0-60, and 45-0-0) fertilizers, and a seed mixture over selected critical areas (Figures 2-A and 2-B). The pelletized lime and fertilizer were bulk transported to the loading area in 25-ton frame trailers. These materials were loaded separately into the aerial spreader by rear dumping through the truck's grain door. The spreader was loaded with seed by hand dumping 50-lb bags. The treated minesites were all located within a 1½ mile radius of the loading area. Average direct costs for spreading 120 tons of pelletized lime over 60 acres was \$22,639 (\$377 per acre); 25 tons of fertilizer over 133 acres was \$9,238 (\$70 per acre); and 2.5 tons of seed over 67 acres was \$6,067 (\$91 per acre) (Table 6).



A. During aerial treatment of an abandoned manganese surface mine in Smyth County, Virginia, August 1985.



B. After aerial treatment of an abandoned manganese surface mine in Smyth County, Virginia, June, 1986.

Figure 2. Aerial seeding and fertilization is a practical approach for revegetating disturbed lands.

Table 6. Aerial treatment activities breakdown on abandoned manganese mine lands in southwest Virginia.*

	Quantity	Direct Costs	Cost Percent
Seed mixture	2.5 tons	\$ 5,655	15
Fertilizer	25.0 tons	5,733	15
Pelletized lime	120.0 tons	5,938	16
Flight time** (Bell Huey 204-B)	20.0 hours	13,000	34
Stand by (mechanic, fuel truck and operator)	4.0 days	2,858	8
Ground crew*** and vehicles	4.0 days	4,760	12
TOTAL		\$37,944	100

* Materials were spread during one treatment period: 8/25/85 to 8/29/85.

** Includes 5.5 hours of ferry time to and from the jobsite.

*** Include crew per diem costs.

SUMMARY

Aerial broadcast treatment of seed and fertilizer offers a practical approach for revegetating disturbed lands. The major advantages of this technique follow:

- It is cost-effective; about \$210/acre for an application of 500 lb of high analysis fertilizer, and 85 lb of an acid-tolerant seed mixture; about \$100/acre for a supplemental application of 500 lb of fertilizer.
- It overcomes site accessibility problems.
- It does not require building access roads that possibly could cause additional environmental damage.
- Aerial treatments can be conducted without damage to existing vegetation.
- Large amounts of materials can be applied in a timely manner.
- Costs of seedbed preparation can often be avoided if aerial seeding is conducted during freezing and thawing periods.
- Results are generally good if appropriate rates of materials are applied during timely seasonal conditions.

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USE OF EXPANSIVE AGENTS ON AML PROJECTS

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INTRODUCTION

There are many reclamation projects that require the fracturing and removal of rock and boulder materials in order to abate a problem. This report presents a discussion on the application of an expansive agent to fracture large boulders that had fallen off the highwall of abandoned mine openings. These boulders were blocking a local road and stream channel. It is believed that this was the first application of an expansive agent on AML projects to fracture rock materials.

The contractor is often faced with selecting a method or means to fracture and remove rock materials in confining conditions. The selection decision process involves the consideration of many variables including not only costs, but also safety and environmental constraints. In AML emergency projects, the most economical method is not always consistent with public safety and the environment. Usually the protection of the public and their structures are the controlling factors.

There are many methods of fracturing rock materials. In a 1982 report by the Corps of Engineers, there was a listing of sixteen different methods to fracture materials. These were listed as:

Blasting

1. Explosive
2. High pressure carbon dioxide blasters
3. Acetylene - air rock breaker

Cutting

4. Diamond saws
5. Powder torches
6. Thermal lances
7. Powder lances
8. High pressure water jets
9. Electric - arc equipment

Impacting

10. Hand-held breakers
11. Vehicle-mounted breakers
12. Water cannons

Pre-Splitting

- 13. Concrete splitting
- 14. Expansive agents

Mechanical Spalling

- 15. Hydraulic rock breakers
- 16. Spallers

The most common method employed in general construction is explosive blasting. This method employs the rapid expansion of gases confined within a series of boreholes to produce fracturing and removal. In general, blasting is the most efficient in fracturing and removing large volumes of materials. However, a major consideration is the safety aspects of handling and useage along with the effects on structures and humans. These effects are from the rapid release of energy in the blast. This energy is released in the form of ground vibration, air blast, and fly rock. Due to the problems in the past, criteria has been established by regulatory agencies which set limits to prevent hazards and structural damage. Even with this criteria, sometimes it is extremely difficult to employ blasting on certain projects.

This report relates the experience on a particular AML project, known as the Timmie Davis Landslide, where the contractor selected the use of an expansive agent. The contract specifications were developed to allow the contractor to choose the method of fracturing to be employed. It is also the intent of this report to provide a transfer of technology regarding the application of expansive agents. The report is not to be used to endorse any particular materials or manufacturer.

PROJECT DETAILS

The Timmie Davis Landslide emergency AML project consisted of removal of fallen boulders and stabilizing abandoned mine openings. The abatement need was created by the failure of rock overburden from the removal of coal by underground mining methods. The overburden consisted of a massive sandstone strata. During the mining phase, reported to have occurred in the early 1940's, openings were driven to the outside on the opposite end of the main entries to provide access for supplies.

Recently the outside coal support deteriorated from weathering and stress to where a large rock fall occurred. The rock released along fractured joints in the sandstone. The rock fall blocked a local road located in a narrow valley, also containing a perennial stream that flowed between an existing residence and the road. The rock fall came within 20 feet of the house. The stream was partially blocked and encroached into the yard. The streambed was then used as a road for access by residences upstream of the rock fall area. A 4-inch gasline was broken and buried by the rock fall. The project site was located north of Mount Gay, Logan County, West Virginia, on a tributary of Demsey Branch, some 3,000 feet north of West Virginia Southern Community Campus.

The project was investigated, designed and contracted for construction by the Eastern Technical Center of the Office of Surface Mining.

DESIGN

The design solution for the abatement was to remove the fallen rock, backfill the entries, reconstruct the road, reconstruct the channel, and reconstruct the yard. There were several restrictions that would control the method of removal of the larger boulders (12 ft x 20 ft x 11 ft). These were: 1) the nearness of the residential structures; 2) overhead utilities; 3) underground gas and water lines; and 4) the need to maintain access and a stream channel. Three fracturing methods were debated during the specification development: 1) blasting; 2) impacting; and 3) the use of an expansive agent.

The specifications developed were a performance type, that is, the contractor was made aware of the restrictions and given the option to employ the most feasible method. Limitations were established regarding explosive blastings. These included: 1) a peak particle velocity of less than 2 inches per second at the nearest structure; 2) an air blast limit of 129 dB; 3) no fly rock (using matting); 4) a pre-blast survey; and 5) monitoring to assure that limitations were not exceeded.

CONSTRUCTION

The construction was awarded on the basis of the low bid to Pawnee Construction in Logan, West Virginia. The difference between the low bid and the second bid was \$7,000. Using the flexibility provided in the contract, the contractor's bid was based on using an expansive agent (a non-explosive demolition technique) to fracture the rock boulders to where they could be handled by a normal end-loader.

On this particular project, the material utilized came under the distributor name of "Bristar". This material is distributed in a 44-lb box containing four 11-lb bags. The material was mixed with about 1.3 L of water per bag to form a slurry which was loaded in pre-drilled holes.

The contractor drilled 1 3/4-in holes on 15- to 18-in centers at 75% of the depth using a hand-held pneumatic jack hammer. The materials were mixed in small buckets and poured through a funnel.

The contractor anticipated an outside temperature range during the contract period from 30° to 60°F. Therefore, the supplier furnished the Grade 200 Bristar. Most fracturing occurred within a 24-hour period. The fracture first occurred as a hairline crack initially, and grew to 1/4-inch size. No unusual construction problems were encountered.

The cost advantage to the contractor was realized from the need not to get blasting insurance, the need not to perform pre-blast surveys, and the need not to perform monitoring. The second low bidder indicated he intended to use explosive blasting.

The nuisance of air blast, ground vibration, and fly rock was also eliminated for the property owners. Approximately 400 yd³ was fractured and removed using 924 lbs of Bristar at a materials cost of \$2,800. The construction was performed in the following phases:

1. Drilling holes.
2. Mixing materials.
3. Filling the holes.
4. Allowing a curing time.
5. Secondary demolition.

The secondary demolition on this project was the use of an end-loader to break apart or separate the cracked rock and load the rock. This process is sequenced in the photographs that follow.

TECHNICAL ASPECTS

This section of the report presents some physical, chemical, and engineering properties of expansive agents used for demolition. Most of the information was extracted from suppliers' publications and is presented to give the designer and contractor an understanding. The Office of Surface Mining does not take credit nor cannot guarantee the technical accuracy of the information.

PROPERTIES

An expansive agent used for fracturing materials such as concrete and rock is also sometimes referred to as non-explosive demolition materials. It is a light gray powder consisting of a special type of inorganic lime compound having a chemical composition similar to ordinary Portland cement. The comparison of Bristar is contained in Table 1.

Table 1.

Chemical Component	Bristar	Portland Cement
Silicon (Si)	4.0%	10.2%
Aluminum (Al)	1.2%	2.9%
Iron (Fe)	0.7%	2.1%
Calcium (Ca)	58.6%	46.5%
Magnesium (Mg)	0.4%	0.8%
Sulphur (S)	1.6%	0.8%
Oxygen (O)	32.0%	35.4%

It is believed these types of materials began being used in the USA in 1980 to fracture concrete. While there may be more manufacturers and materials, this report is based on two that are currently available and distributed nationwide.

Bristar is manufactured by Onoda Cement Limited and distributed by Construction Products and Service, Marietta, Georgia, 404-429-0008. A competitive product is "S-Mite" manufactured by Sumitomo Cement Company and distributed by Sumitomo Canada Limited, Vancouver, British Columbia, 604-682-2256. Both products are manufactured in Japan.

These agents derive their fracturing capabilities from expansive stresses that are generated in the process of crystallization by means of the chemical reaction of hydration. An expansive stress of 3,000 tons per m² can be generated within a 20- to 24-hour period (3,000 t/m² = 3,870 psi). The agent expansive stress is exerted on the rock to be fractured as a compressive

stress causing tensile stress working at right angles (Figure 1). Since the tensile strength of rock is much less than the compressive strength (1/10 to 1/40), a tensile failure occurs and a crack is generated. The cracks are generated as connections between holes.

As mentioned, the expansive stress is from a chemical reaction of hydration which is influenced by the rock temperature (Figure 2). To make the agent more flexible, the manufacturers have developed different types or grades to be used under certain temperature ranges.

The expansive stress continues to increase with time even though sufficient strength is gained to fracture rock in 12 to 24 hours, the expansive stress also increases in direct proportion to the hole diameter.

HOLE DESIGN AND PATTERN

The optimum design is based on using a drill pattern with the minimum number of holes using the least amount of materials. The drill pattern will vary with the objectives for each project. For fragmentation, the square pattern is drilled on centers of 12 to 30 inches, depending on the hole size, rock characteristic, natural seams etc. (Figure 3). For normal useage, a hole diameter from 1 to 2 inches is recommended by the suppliers. Generally vertical holes are utilized; however, slant, horizontal or even up-slant holes can be drilled and filled. To obtain optimum fragmentation, drilling holes in opposition to the bedding planes or weak zones should be utilized.

QUANTITY USEAGE

The quantity useage on a particular project can be developed using the hole diameter, hole depth, and hole spacing. Wide variations can be expected from project to project. The kind of removal equipment (secondary demolition) will usually have the most influence on quantity useage. If a 10 yd³ boulder has to be fragmented for removal with small equipment, more material would be required because of more holes, than if the boulder was only required to be pre-split and left in larger blocks which could be handled by larger equipment.

Once the hole layout is determined and hole diameter is selected, the quantity useage can be determined using the following lb/ft table.

Table 2. Unit: lb/ft (data from Sumitomo Cement Company).

Water Ratio (%)	Hole Diameter (inch)							
	1-1/8	1-1/4	1-3/8	1-1/2	1-5/8	1-3/4	1-7/8	2
25	0.766	0.946	1.144	1.362	1.598	1.854	2.218	2.421
26	0.753	0.929	1.124	1.338	1.570	1.821	2.091	2.379
27	0.740	0.913	1.105	1.315	1.544	1.790	2.055	2.338
28	0.727	0.898	1.086	1.293	1.517	1.760	2.020	2.299
29	0.715	0.883	1.068	1.272	1.492	1.731	1.987	2.261
30	0.704	0.869	1.051	1.251	1.468	1.702	1.954	2.224

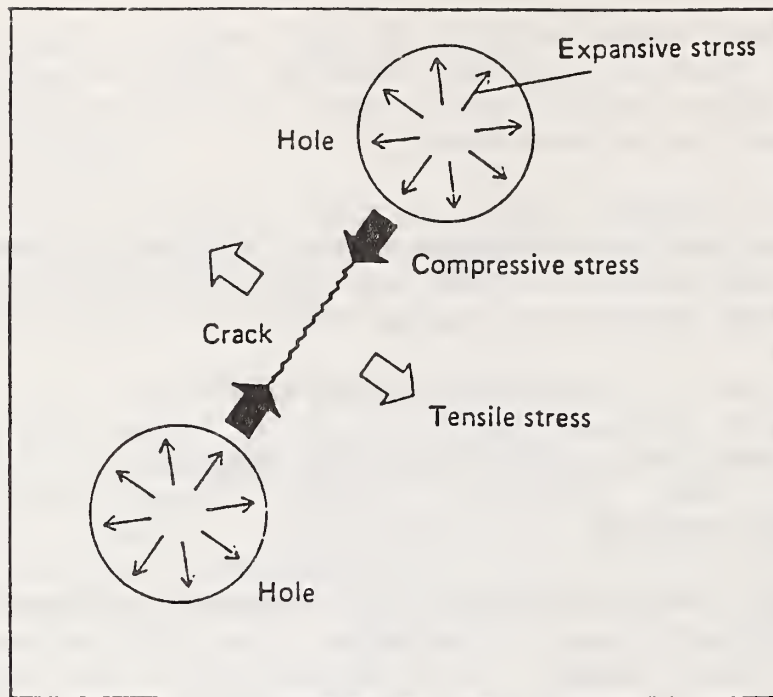


Figure 1. Demolition mechanism.

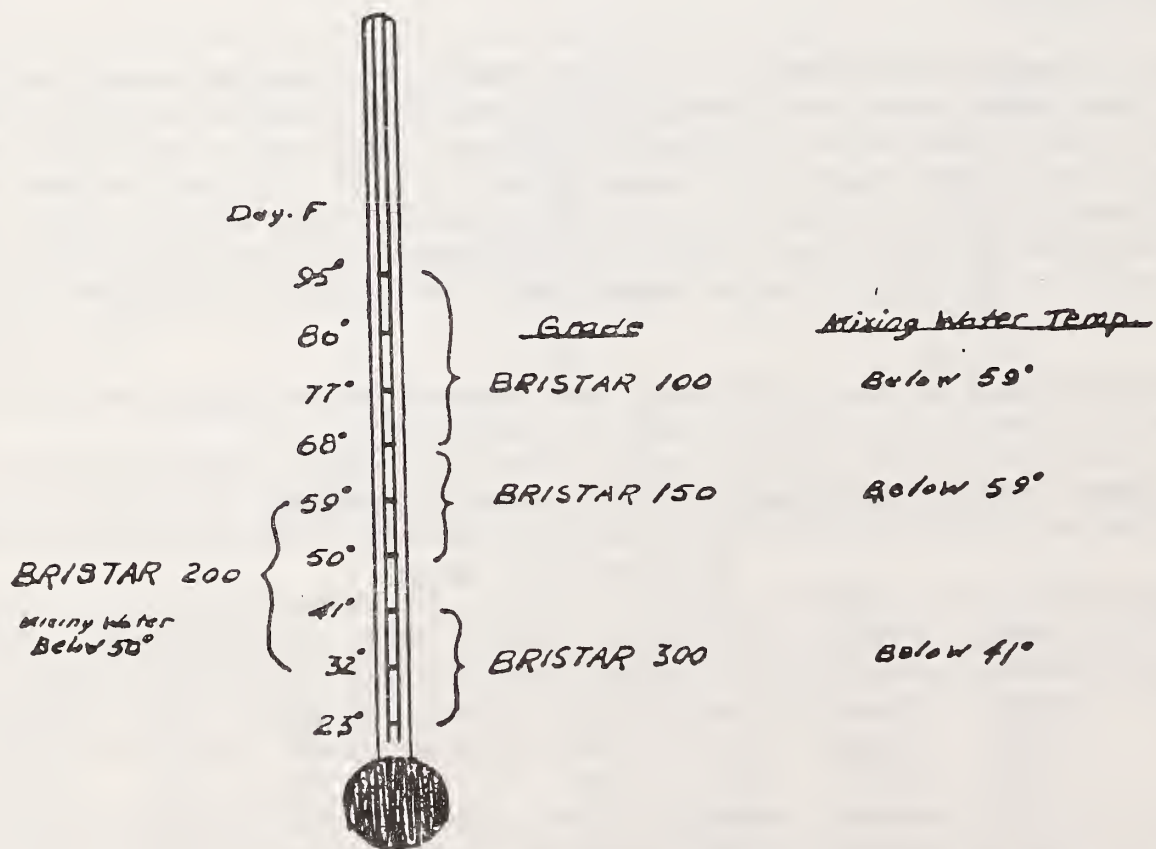


Figure 2. Grade/temperature application of Bristar.

The quantity would be determined by taking the total footage to be drilled times the lb/ft factor at the water mixing ratio. Usually a water ratio of 27% can be used for estimating.

For an example problem, let's say 1.5 in of 150 ft of holes (taking the number of holes times their length) is needed to be filled. Using 1.5 in at 27% water ratio, 1.3 lb/ft will be required. This multiplies out to 195 lbs.

Since the materials are shipped in 44-lb boxes, by dividing the 195 lbs by 44, it would require approximately 4.5 boxes. The volume of water required to obtain a certain mixing ratio can be obtained from the following table.

Table 3. Relationship between water mixing ratio and volume of water of S-Mite (data from Sumitomo Cement Company).

Water Mixing Ratio (% wt)	----- Volume of Water Needed With-----			
	10 kg S-Mite	20 kg S-Mite	22 lb S-Mite	44 lb S-Mite
25	2.5 L	5.0 L	88 oz	176 oz
26	2.6 L	5.2 L	92 oz	183 oz
27	2.7 L	5.4 L	95 oz	190 oz
28	2.8 L	5.6 L	99 oz	198 oz
29	2.9 L	5.8 L	102 oz	205 oz
30	3.0 L	6.0 L	106 oz	212 oz

For boulder fragmentation, the suppliers of Bristar indicate a range from 3.1 to 6.7 lb/yd may be required. On the project a 10 yd³ boulder was fractured using 3 lb/yd³. When boulders were pre-split less amounts of materials were used. The materials cost ranges from \$3 to \$4/lb.

SAFETY PRECAUTIONS

The U.S. Department of Labor (MSHA) lists the materials as a chemical mixture (calciumsilicate, calciumoxide, calciumsulfate and others) and indicates the effects of exposure is similar to Portland cement. First-aid procedures are washing with water for skin contact and doctor examination for eye contact. Rubber gloves and safety glasses are indicated for protection. The materials can spout out of the hole during curing so peering down the hole should be prevented. Due to its strong alkalinity, the material will cause rashes when contacted with skin.

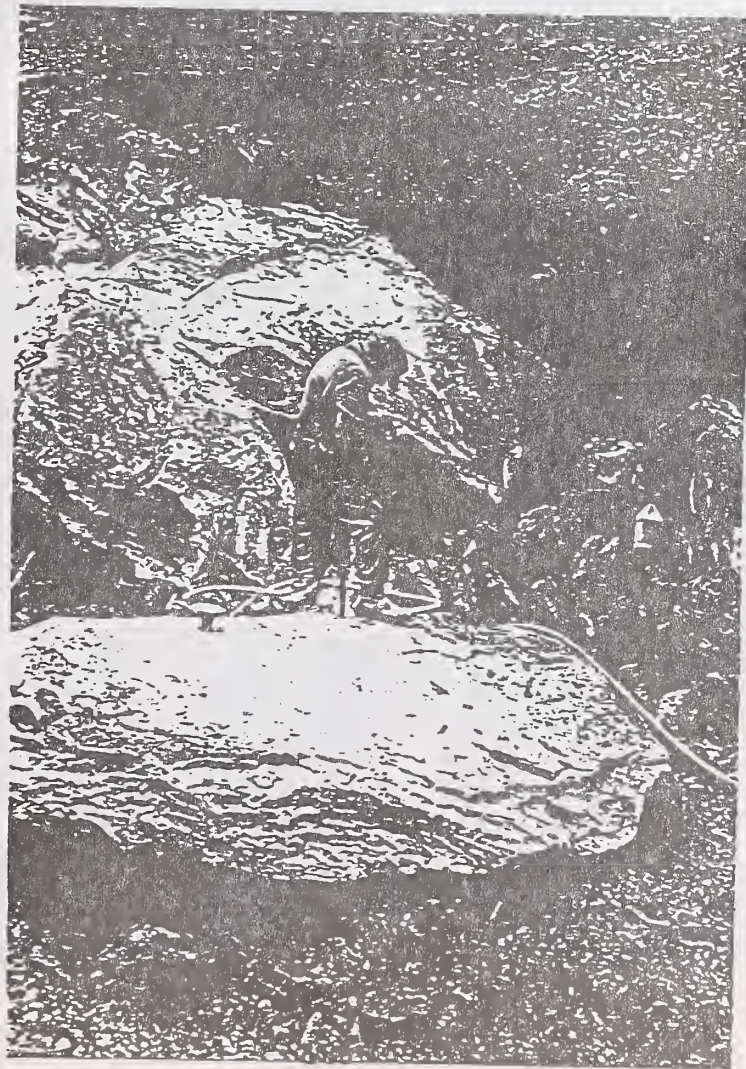
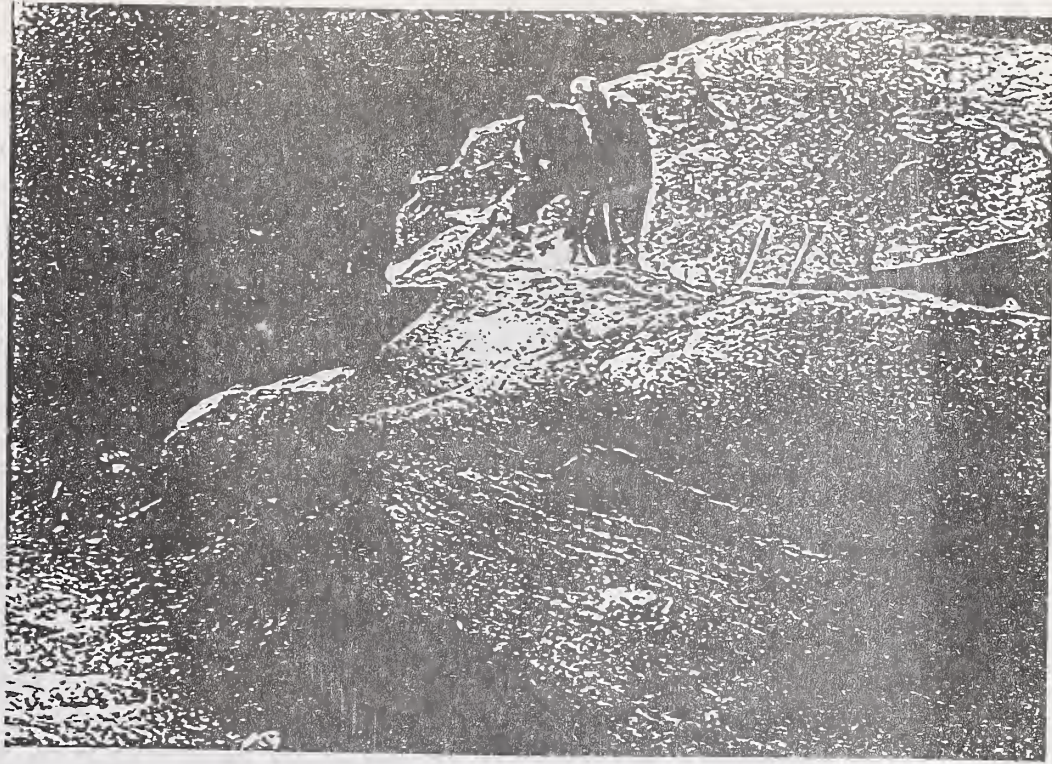
The material is normally available in 44-lb boxes in smaller weighed waterproof bags (11 or 22 lb). These boxes can be shipped through the normal courier services.

SUMMARY

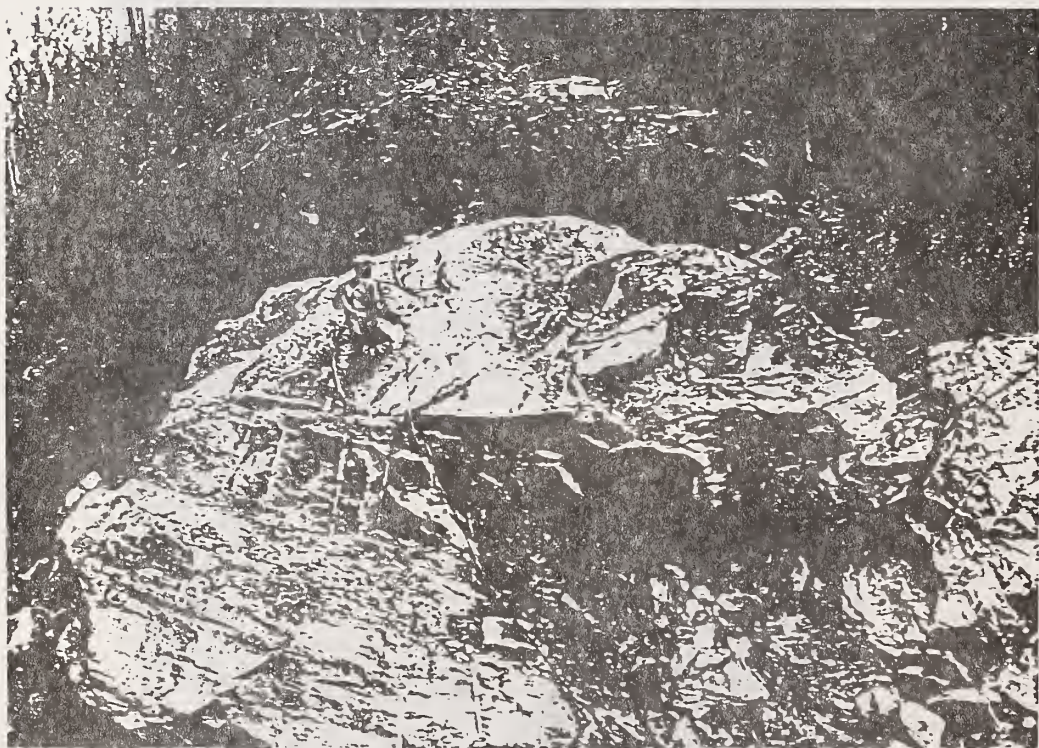
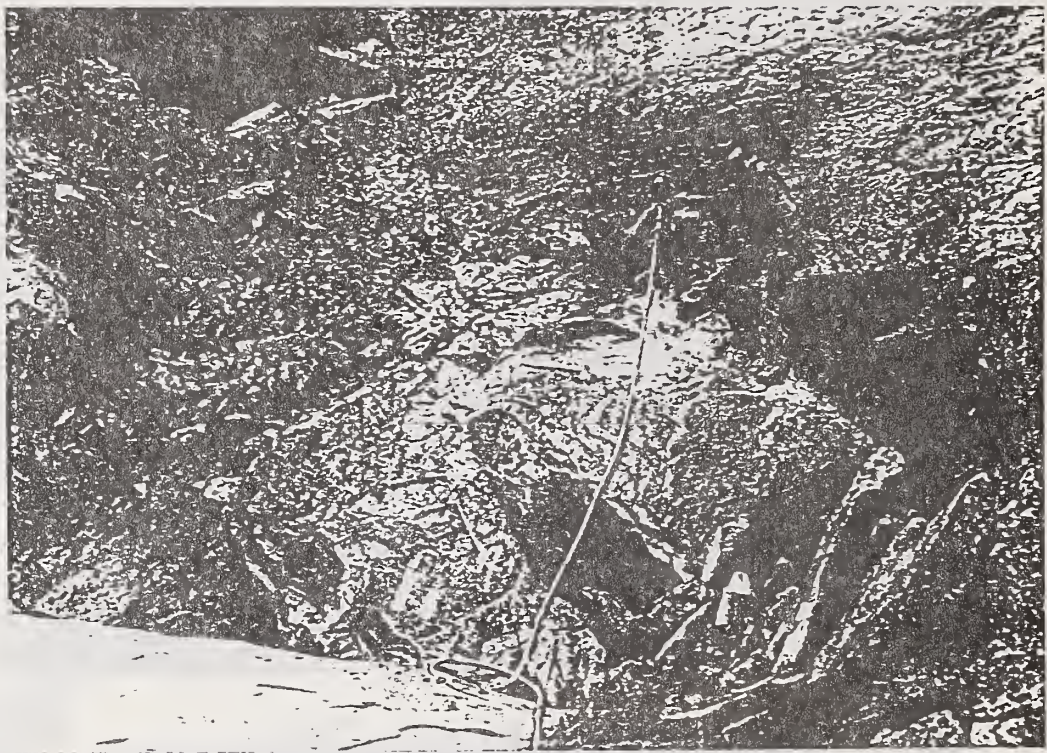
The use of an expansive agent as a non-explosive demolition material on AML projects is a feasible method for fracturing boulders, pre-splitting rock faces, and cutting rock ditches. The materials are readily available and can be used with little training. The best approach for contracting purposes is to allow the contractor to employ this method as an alternative to other methods available for the purpose once limitations are established for public safety and protection.

P R I O R T O A M L W O R K





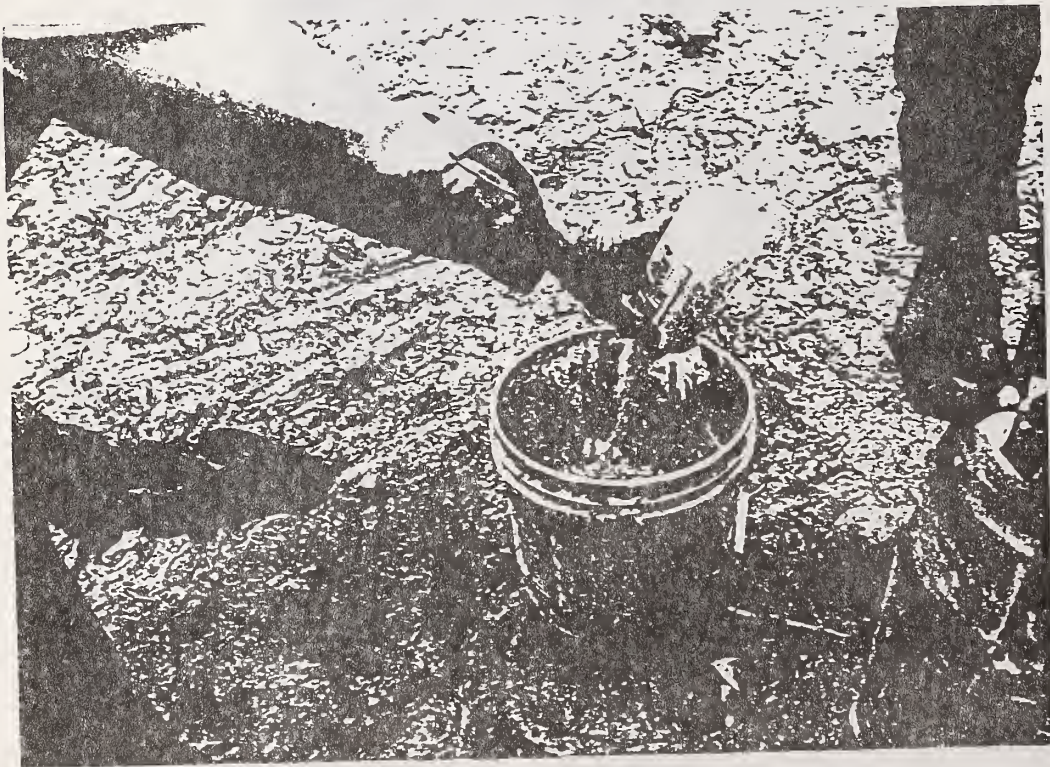
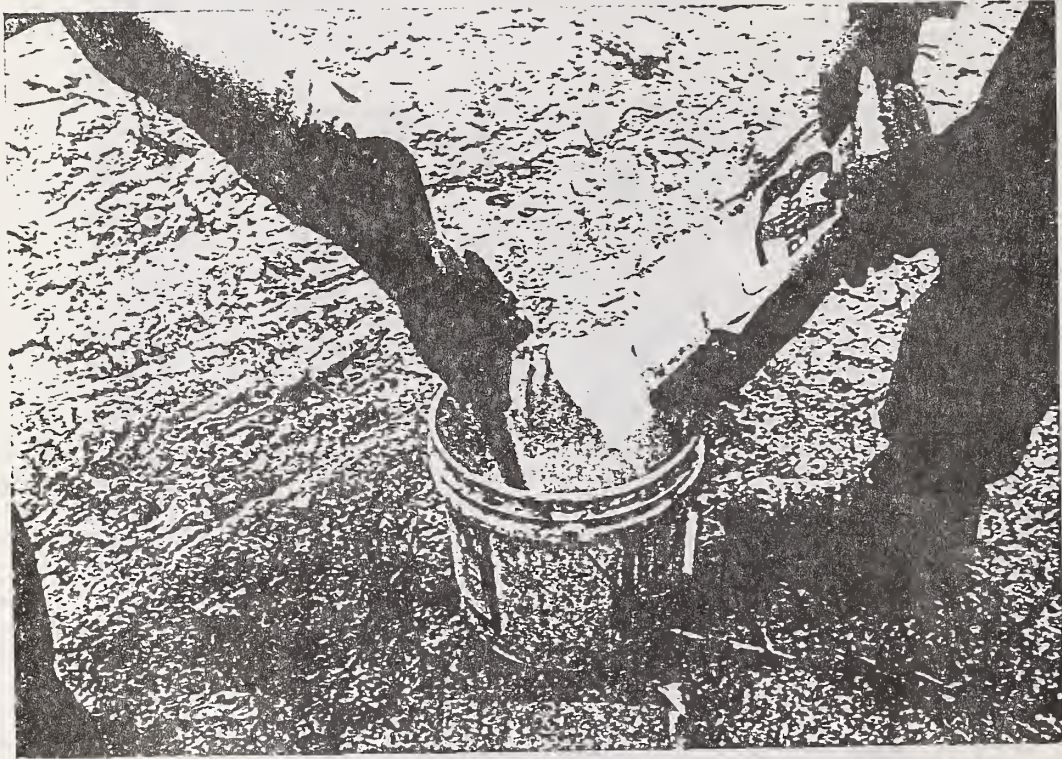
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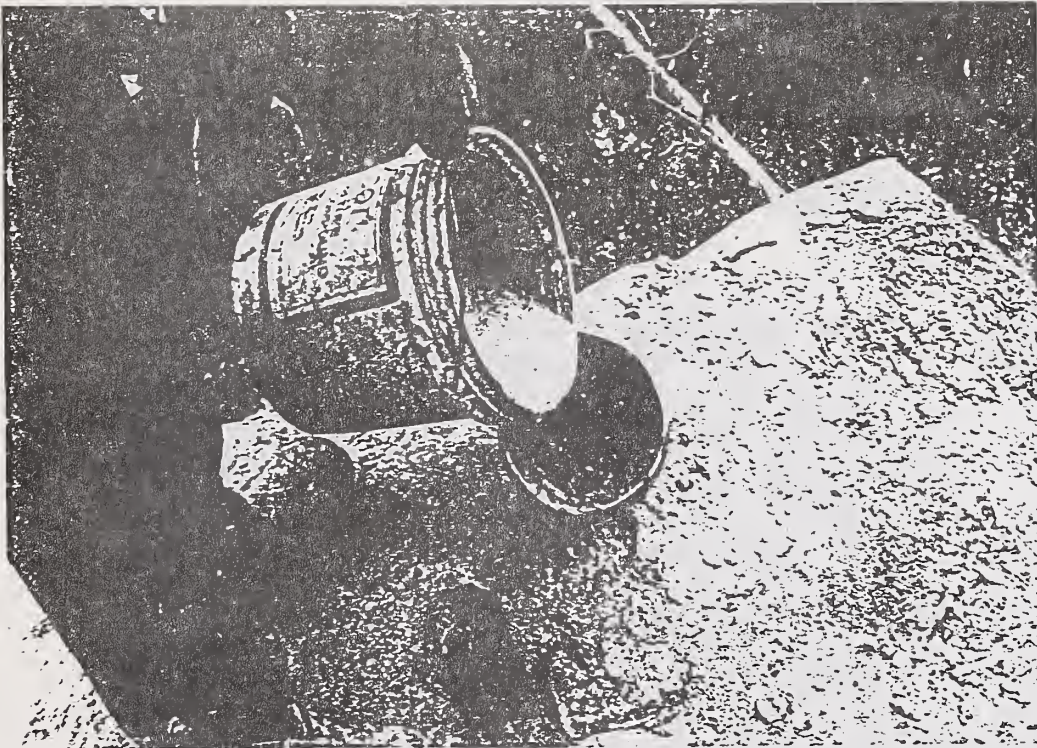
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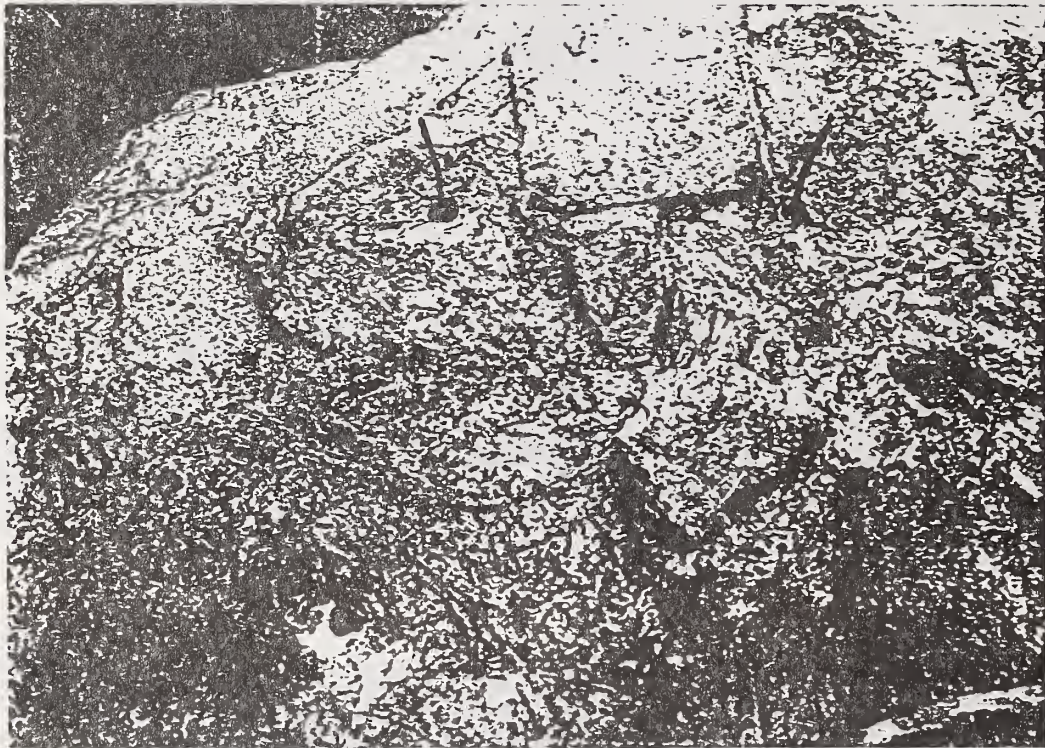
MIXING AGENT
AND WATER



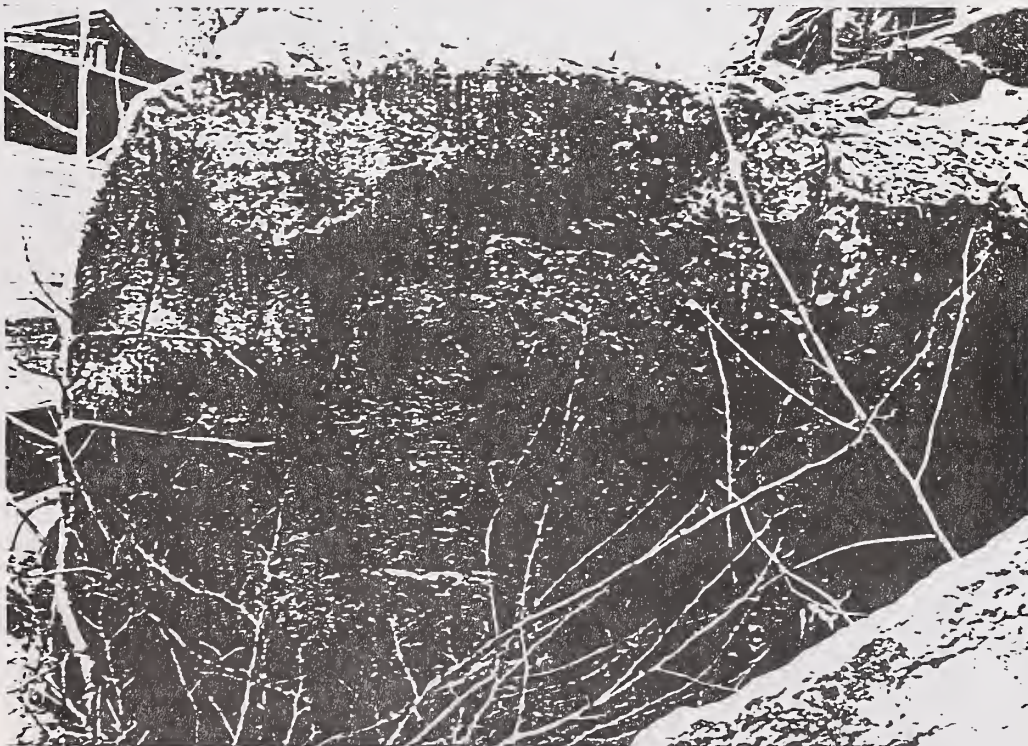
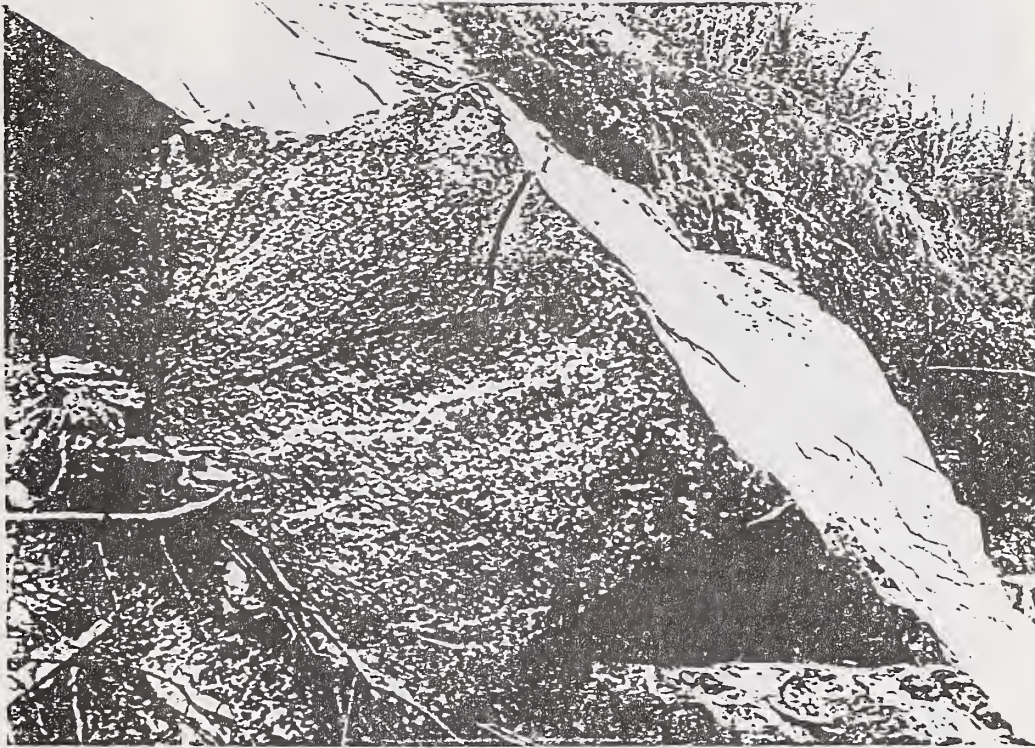
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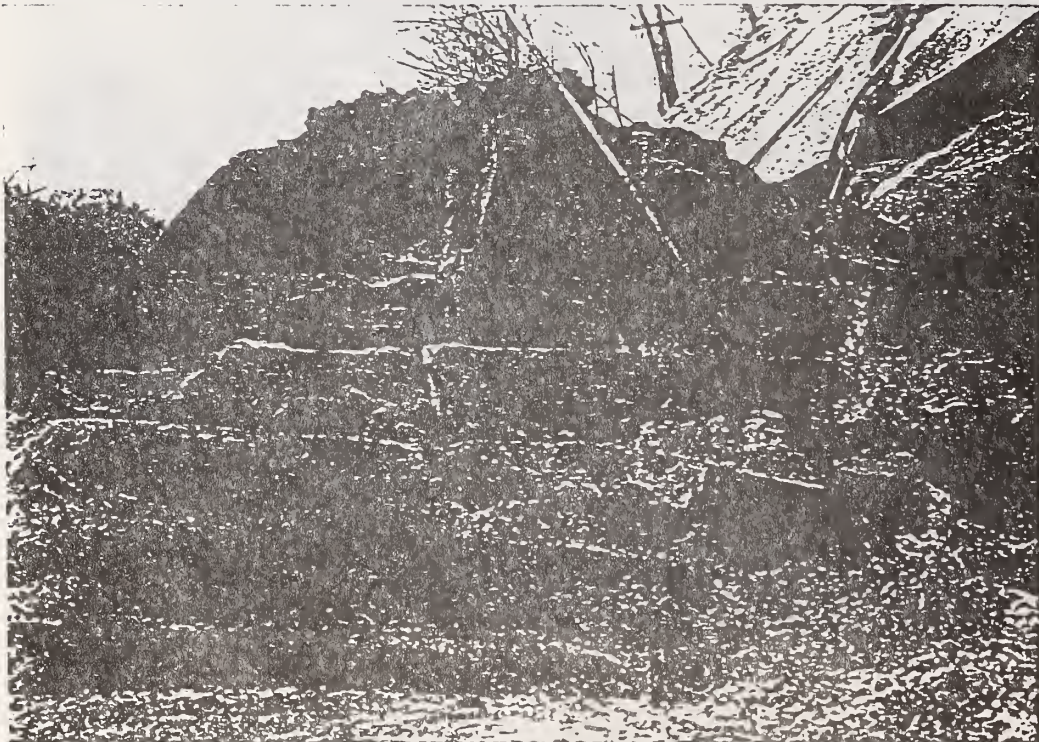
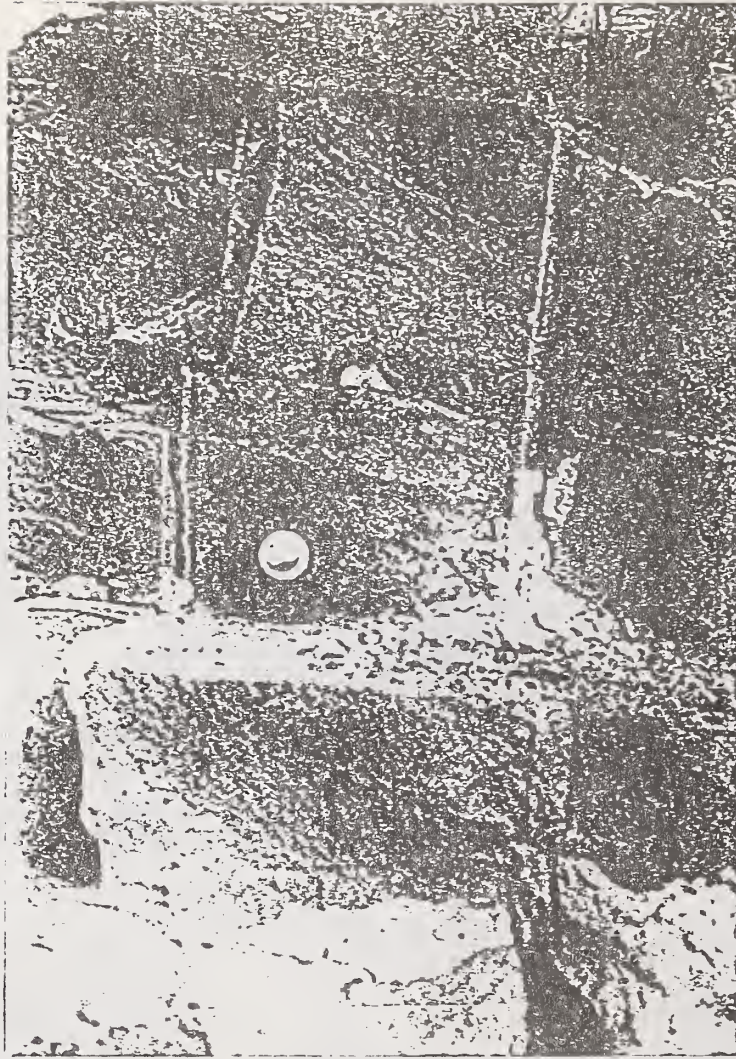


C U R I N G T I M E

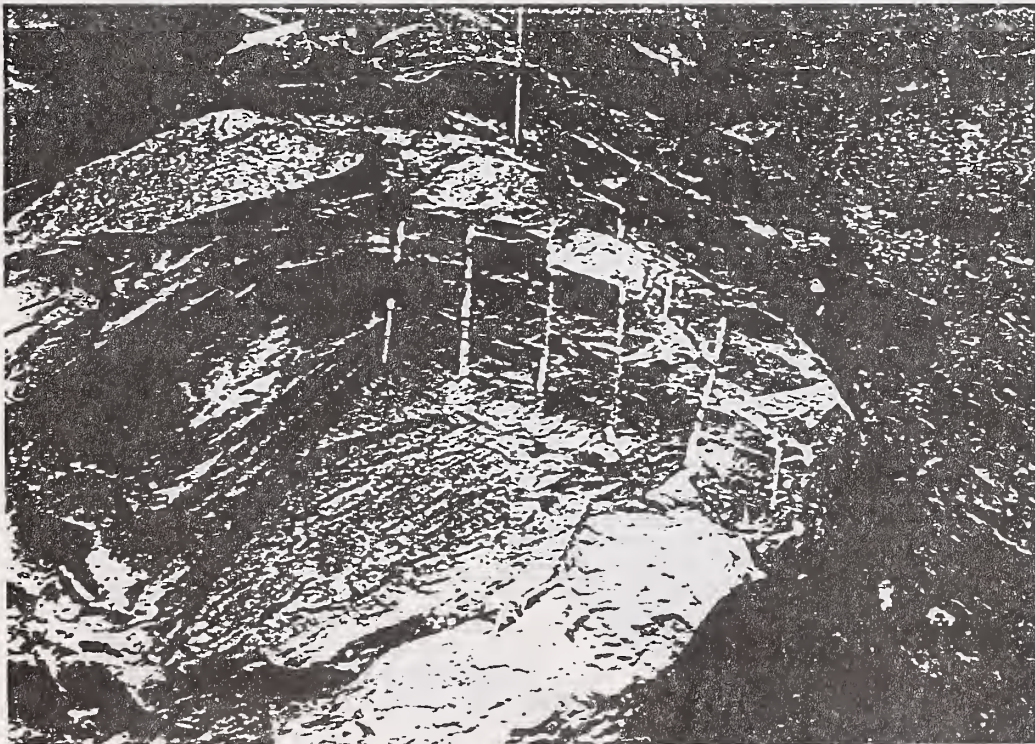
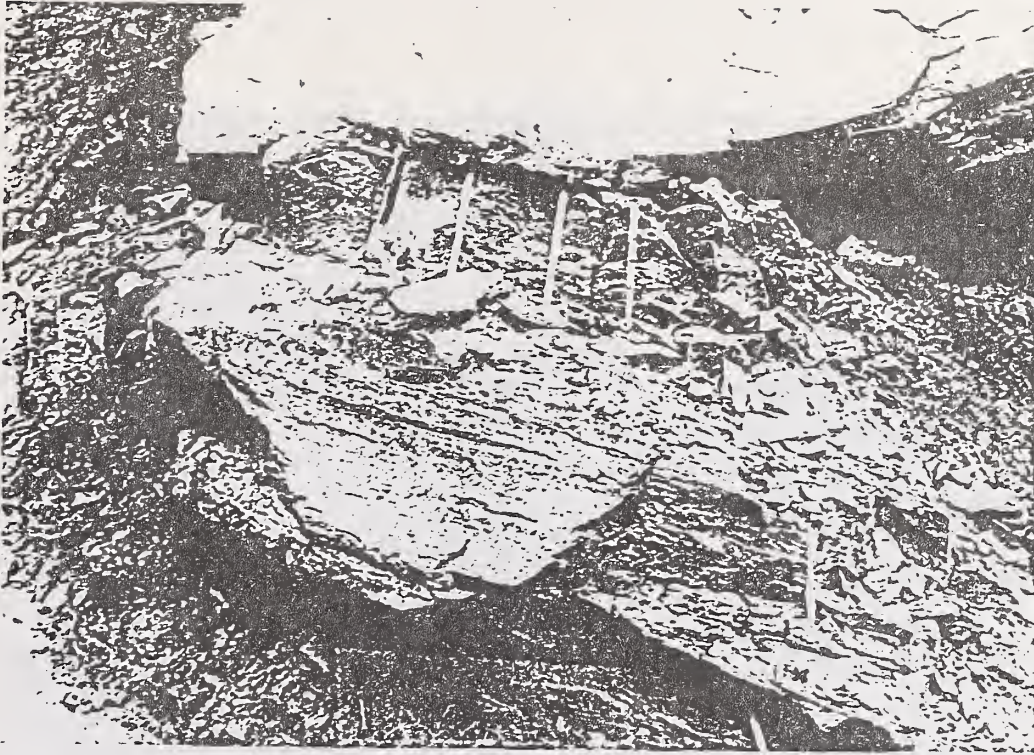


AGENT WORKING





DEMOLITION



S E C O N D A R Y D E M O L I T I O N



DEMOLITION COMPLETE
ROADWAY AND CHANNEL
RESTORED



THE FEDERAL APPROPRIATION PROCESS: TIMING AND ISSUES

J. P. Crumrine, Chief
Division of Planning and Budget
Office of Surface Mining Reclamation and Enforcement

INTRODUCTION

The Federal budget process does not begin; it is and it will be. For example, during the month of August 1986, my staff is watching the rate of obligations for Fiscal Year 1986, writing the instructions to the field offices for development of the Fiscal Year 1987 operating budget, and preparing the submission to the Office of Management and Budget (OMB) of our Fiscal Year 1988 budget request. Working simultaneously on three different budgets is not unusual; it is the way in which the Federal process typically works.

In order to distinguish the particular budget to which one is referring, several sets of terms have developed. There is "current" year (1986), "budget" year (1987), and the "planning" year (1988). The year in which we are operating (i.e., current) is 1986, the year whose budget Congress is reviewing is 1987, and the year for which we are making plans is 1988.

There are also the budgetary references of "formulation", "presentation", and "execution". "Formulation" means the planning or developing of the budget request within the executive branch prior to submitting it to Congress in January of each year. "Presentation" refers to the stage of the process when Congress reviews the request and then votes on the appropriation level. "Execution" refers to the final stage in which the agency spends the funds for the purposes for which they were appropriated.

It is this latter set of terms which are more frequently used and which I will use to describe the budgetary process. During this discussion I will use the Abandoned Mine Reclamation Fund (AMRF) as an example of what happens throughout the process to one appropriation account.

FORMULATION

This stage ends with the submission of the President's budget request to Congress in January. It has no beginning. At the Office of Surface Mining Reclamation and Enforcement (OSMRE) and the Department of the Interior, this stage formally starts with a guidance memorandum from the Secretary. In this memorandum, the Secretary outlines his major objectives to be accomplished in the next year. For Fiscal Year 1988, this memorandum was signed on April 8, 1986. This is nearly 18 months prior to the beginning of Fiscal Year 1988 and 30 months before its end.

With so much time between these initial planning efforts and the beginning of the fiscal year, many circumstances do change and ultimately modify these early planning ideas. For example, a state's needs or capabilities could

change or the amount available in the current year may change which could result in a new base for the following year. While analysis is meant to be objective and scientific, it can never be omniscient. The intentions of the winter of 1986 may naturally evolve into some quite different concepts of results by the late summer of 1988. Thus, flexibility is an important aspect of the formulation stage.

After the various Interior agencies receive the Secretary's guidance, they propose a budget request which must be reviewed by both the program Assistant Secretaries and the Assistant Secretary for Policy, Budget, and Administration. This occurs during the months of May and June. By July, the process is ready to move to the point where the Under Secretary and Secretary become directly involved. There are meetings with these officials over the major budget issues, including the development of a strategy for presenting the budget to OMB.

It is during this period, before the Secretary formally submits the budget to OMB, that the size of the AMRF request is debated within the Department. Questions are asked about the States' needs, requests, and capabilities. The Secretary's objectives for encouraging the States to manage the abandoned mine problems are balanced against other Interior Department objectives such as stewardship of natural resources, Indian health and safety, or Territorial governments.

After the Secretary makes his final decisions, these are transmitted to the agencies for preparation of the Budget Estimates. This is the name of the formal document which OMB uses to review the budget requests for each agency. When the estimates are received in OMB, they are referred to the staff of budget examiners responsible for the programs involved. All the knowledge that the examiners possess about the agency--based on long-term analysis, field investigations, special studies, and conferences held with agency officials--is brought to bear at this time. The examiners identify significant program, budget, and management issues to be raised for discussion with agency representatives at hearings conducted by OMB during September and October. After the hearings are completed, the examiners prepare summaries of the issues and their recommendations for the OMB Director's Review. This Review provides an opportunity for the principal officials of OMB to obtain from the examiners an understanding of agency program aspirations and budget requests. An analysis of the significant issues, such as the proposed level of funding for the AMRF and the relationship of the agency requests to the planning targets recommended for the agency as a result of OMB's Spring Planning Review, is presented at the Review. The Director's Review process is directed toward applying the President's policies to each agency's budget request.

Following the Director's Review, the most critical issues or program matters are placed before the President. He is faced with the task of recommending a budget that meets the most urgent needs of the country and still is prudent within the constraints imposed by the availability of resources. Once the President has met with the Director of OMB, the agencies are notified of the decisions and begin the preparation of the Budget Justifications for the Congress. This usually occurs in November and December, nearly 10 or 11 months before the fiscal year begins and 20 some months before it ends.

PRESENTATION

This stage of the process begins with the announcement of the President's budget request for the next fiscal year. Through 1986, it was required to be transmitted to Congress within 15 days after the start of each new congressional session in January. Beginning in 1987, it is required to be transmitted by January 4.

Since 1974, there have been several significant legislative changes to the traditional budget process. The Congressional Budget and Impoundment Control Act of 1974 (P.L. 93-344) began Congress's attempt to focus on overall budget totals. It is the first legislative branch effort to relate individual appropriation actions to one another within a general set of priorities. To aid in this process, the Act established a new committee on the Budget in each House and a new, professionally staffed Congressional Budget Office (CBO).

Last year, Congress enacted The Balanced Budget and Emergency Deficit Control Act of 1985 (P.L. 99-177). This is commonly called the Gramm-Rudman-Hollings (GRH) Act. This legislation requires Congress to confront and to deal with the cumulative effects of all its individual budget related actions. Thus, it forces Congress to address overall budgetary priorities.

Although Congress has some flexibility to extend the time it has to make its budget decisions (e.g., enact a Continuing Resolution), Congress must make all of its decisions in the nine months from January to September. Since Congress is composed of 535 individuals and multiple committees, this becomes a very complex and cumbersome process. However, to the budget professional, there is more turbulence on the surface than below.

First, there are hearings scheduled by the legislative (i.e., other than the appropriation) committees which have oversight responsibility for budgetary policy. For OSMRE, these are the Interior and Insular Affairs Committee in the House whose Chairman is Representative Morris Udall of Arizona, and the Energy and Natural Resources Committee whose Chairman is Senator James McClure of Idaho. They will typically hold hearings in late February. Generally, these hearings raise questions concerning the major initiatives or other significant changes in OSMRE's budget and program policies. These committees are responsible for making a recommendation to the budget committees concerning funding levels for individual agencies and programs.

According to the GRH Act, the budget committees are required to prepare a Budget Resolution for the next fiscal year by the preceding May. This year, the Budget Resolution was finally approved in July. Within the totals, the Resolution identifies subtotals for various programmatic areas such as foreign aid, defense, or natural resources. The Budget Committee hearings, transcripts, and reports provide the information explaining the assumptions for each subtotal. For example, the Fiscal Year 1987 Resolution assumes that all Interior agencies will receive an appropriation equal to their 1987 requested level of funds minus four percent. That results in a total of \$182.9 million for the AMRF and \$144 million for State Reclamation Grants.

Behind the turmoil of the budget resolution process, the appropriation process is relatively stable from year to year. It is important to note that although the appropriation committees are not bound by the Budget Resolution, their

latitude has been restricted by the GRH Act. The GRH Act changes some of the parliamentary rules concerning the relationship between the Budget Resolution and the individual appropriations bills. Individual members have more flexibility to object to appropriation bills on the basis of inconsistency with the overall budget totals. The Senate is even more constrained by the new rules than the House.

However, the review of the President's budget request by the appropriation committees has not been affected by the GRH Act. Normally, this process begins with the Secretary's appearance in February at the appropriation hearings and follows with hearings for individual agencies. This year, the House had its OSMRE hearing in March and the Senate held its OSMRE hearing in April. After the hearings, the agencies usually have hundreds of questions to answer for the record and many inserts to prepare for the transcript. This material is printed for the record and provides the basis of the Subcommittee's review of the President's request.

In addition, the agencies respond to formal statements provided to the Subcommittees and to questions from members of Congress. These responses are called capability statements. They are intended to explain the likely effects of a proposed change to the budget request, whether it is feasible to accomplish, and whether the agency is capable of using the proposed funds. Sometimes these statements address broader policy issues such as the AML inventory rather than budget changes.

According to the GRH Act, the House was supposed to have passed all of the 1987 appropriation bills by July 4 of this year. However, only one was actually passed by that date. The Fiscal Year 1987 Interior bill was passed by the House of Representatives on July 31. Although the bill was voted on by the full House, it was the members of the Interior Appropriations Subcommittee and the full Appropriations Committee who had the greatest influence on the bill.

The bill was "marked-up" by the House Subcommittee on July 16. This means that the Subcommittee met and voted on a level of funding for each appropriation account. OSMRE has two appropriations--Regulations and Technology and the AMRF. The Subcommittee members work from proposals developed by their staff. These proposals are based on the President's request, the Agency's Justifications, and the material prepared for and after the hearings. For 1987, the Subcommittee recommended \$232.7 million for AMRF of which \$186.1 million is for the State Reclamation Grant activity.

Shortly after the Subcommittee mark-up, the entire Appropriations Committee votes on the bill. This occurred on July 24. Typically, only matters of national impact or major political differences are taken up at this level. The full Committee relies on the Subcommittee to handle the details of each agency's request.

After the full Committee passes the bill, it receives a rule. Most bills must pass through the Rules Committee and then to the floor of the House. The purpose of the rule is to prevent a member from making a point of order objection which would send the entire bill back to committee. This could occur if an agency or program did not have authorization for its appropriation. This year, the House debate and vote on the Interior bill took place on July 31.

According to the Constitution, all money bills must originate in the House of Representatives. After the House passes an appropriation bill, the Senate begins its work. This is identical in sequence to the House process. The Senate Appropriations Subcommittee marked-up the Interior bill on August 7. The full Committee and the Senate are expected to vote on the bill before the Senate recesses in August.

Once the House and Senate have each passed their own appropriation bill, they must agree on a single bill. As is the case whenever House or Senate versions of a bill differ, the appropriations bills must go to a conference Committee to be reconciled. The report of the Conference Committee can provide very specific direction to the agency which can be as constraining as the actual bill language.

The Conference Committee process can occur either before or after the fiscal year formally begins. Recently, it has frequently occurred after the beginning of the new fiscal year. This means that Congress must first pass a Continuing Resolution which generally allows agencies to continue operations at the prior year's level until a regular appropriations bill is enacted.

One final twist for Fiscal Year 1987 will be the application of the GRH Act. Whether Congress passes a Continuing Resolution or an appropriations bill, there may be another application of the GRH Act. The criterion is whether OMB and CBO estimate the Fiscal Year 1987 deficit to be greater than \$154 million. The GRH Act stipulates that the deficit for that year shall be no greater than \$144 million; however, there is a \$10 million range provided because of the level of precision available for these estimates. At this point, if the automatic reduction procedures were triggered, the percentage decrease would be in the 9 to 11 percent range. This is the percentage by which the State Reclamation Grant activity would be reduced. According to the GRH Act, OSMRE will have no discretion about its application at this level. Since the State Reclamation Grants is a separate activity from the OSMRE operating accounts, there is no ability to trade-off the reduction in operating funds against the reclamation grants. Both activities would incur the same percentage reduction.

EXECUTION

Following the enactment of an appropriations act and before any funds can be legally spent, there occurs an arcane process within the Executive Branch. The interim steps are called "warrants" and "apportionments". This process was established in the 1930's by the Antideficiency Act. This consists of dividing the total available funds into specific amounts available for portions of the fiscal year or for particular projects or activities. It is a violation of law for an agency to incur obligations or make expenditures in excess of the amount apportioned. The apportionment system is intended to achieve the most effective and economical use of the funds available and, for appropriations available for a definite period of time, to prevent the necessity of supplemental or deficiency appropriations.

Each agency is required by law to have a system of administrative controls to: 1) restrict obligations or outlays against each appropriation or fund to the amount of the apportionments of such appropriation or fund; and 2) enable the director of the agency to fix responsibility for the creation of any obligation

or the making of any outlay in excess of an apportionment or reapportionment. In OSMRE, the system of administrative control is based on allotments and allocations made to the responsible personnel in various organizational units. For example, in Fiscal Year 1987, following the decentralization of OSMRE's Grants Administration Division, the Assistant Directors for Eastern and Western Field Operations will have authority to approve grant awards. Consequently, the Deputy Director for Administration and Finance will not allot grant funds to the appropriate Assistant Director. These individuals will now be accountable for ensuring that cumulative grant awards do not exceed the total funds available.

Progress on the budget program is reviewed periodically throughout the year. Today, our current year budget is for Fiscal Year 1986 and on October 1, 1986 the Fiscal Year 1987 budget takes effect. Reports on the status of apportionments and obligations are prepared monthly and more detailed reviews of program accomplishments are also made during the year. Shifts (or reprogrammings) in agency budget plans during the year are frequently required to meet changing conditions--to finance unforeseen emergencies or to provide savings where the workload is less than was estimated or where increased efficiency permits accomplishment at less cost than was anticipated. For example, in Fiscal Year 1985 OSMRE had to propose two separate reprogrammings in order to provide additional funds for emergency reclamation projects. If these reprogrammings had not been approved (by the Department, OMB, and both the House and Senate Appropriations Subcommittees), OSMRE would have been unable to undertake any additional emergency reclamation projects during the summer of 1985. If the agency had proceeded without reprogramming funds, this would have been an Antideficiency Act violation. Funds would have been obligated for an activity in excess of what was legally available.

Individual agencies are responsible for assuring--through their own review and control systems --that the obligations they incur and the resulting outlays follow the provisions of the authorizing and appropriating legislation, as well as other laws and regulations relating to the obligation and expenditure of funds.

Finally on September 30 the fiscal year ends and a new fiscal year begins. Meanwhile, OMB is examining the requested budget for the next fiscal year and the plans for the following year are already being developed. This continuing process is the budget cycle.

BUDGET ISSUES FOR THE ABANDONED MINE RECLAMATION FUND

This section of the paper will discuss the types of budget analysis used to determine the level of funding for the State Reclamation Grants. This applies to every stage from OSMRE's request, to the Secretary's recommendation, to the Appropriations Committees' decisions. It is important to understand that the Abandoned Mine Reclamation Fund and, therefore, the State Reclamation Grants are treated as a regular appropriation account requiring annual Congressional action to make funds available for grants. Although the funds for these grants are derived from the fees on coal production, the AMRF is not a "trust" fund. The AMRF is considered a "special" fund which distinguishes it from the General Fund of the Treasury. By contrast, gasoline taxes are

deposited into the Highway Trust and are automatically available for expenditure in the following year without Congressional action. Within the Department of the Interior, there are a number of other programs treated as trust funds and permanent appropriations. However, the monies deposited in the AMRF can be spent only with prior appropriation by Congress and only for the purposes provided for in the Surface Mining Act. This difference explains why the request level of funding for the Reclamation Grants is an important, significant, and strategic decision to the Secretary, the President, and both appropriations subcommittees. Since the AMRF is not a special permanent appropriation, then the level of its funding request is part of the total request for the entire Department of the Interior.

While planning may start with a finite or specific level, budgeting today begins at the top and is allocated downward. This hierarchical method is used by OMB, CBO, and the appropriations committees. A broad target or ceiling is determined for the higher aggregate level and then disaggregated to the lower levels. This subdivision may go through several levels before finishing.

Within the executive branch, the President's Budget request for 1987 forms the basis for the planning target or ceiling for 1988. Thus, the current policies of the President are projected into future economic fluctuation, but for little else. Shortly after the President's Budget is submitted to Congress, OMB sends the Secretary a "planning allowance" or target for the next fiscal year. Thus, in February 1986, Interior received its planning allowance for fiscal year 1988. The Secretary is instructed to prepare his next planning year budget based on this total allowance. While the Secretary may change his objectives or priorities, or a new Secretary may be appointed, the allowance is still based on the previous year's request.

Whatever the Secretary wishes to achieve in 1988, he must be able to do so within this current allowance or to submit a budget to OMB which is greater than the allowance. Since reclamation grants are a relatively large sum, they are identified by the Department as a significant potential trade-off item to help hold the budget request within the allowance. This is not unusual; similar programs such as construction projects in the Bureau of Reclamation, the Fish and Wildlife Service, and the National Park Service or the Land and Water Conservation Fund or Historic Preservation Grants are treated in the same way.

The reason the AMRF is considered in this category is because the level of funding cannot be identified with a single objectively derived figure. The three most common justifications are the request, need, or capability of the States. While the analyst tries to relate the level of funding to the programmatic purpose or authorizing legislation, he or she needs some measure to bridge this analytic gap. "Request" is not always strictly related to need. To the analyst, it represents what the requestor wants. This could be more or less than what is necessary to achieve the programmatic objective. Ideally, one would want to measure the States' need for reclamation funds. Unfortunately, an empirical measure of "need" is not available. Although the inventory is a surrogate, there are conceptual problems with it.

To the budget analyst, there is also another way to identify need. That is to observe the rate at which the funds are used or expended. For Federal programs, this is called the obligation rate. Obligations are defined as a

binding legal commitment on the Federal Government to pay someone. Therefore, decision makers are prone to conclude that if an agency cannot obligate its funds it must not have an urgent need to use them.

If less appropriations are necessary for the AMRF, more will be available for other Interior programs within the same target or ceiling. It is important to note that this does not mean that the receipts deposited into the AMRF are used for other purposes. It does mean that the overall ceiling is rearranged so that less is appropriated for the AMRF and more ceiling is made available from the general fund for other programs. This type of thinking is not limited to the executive branch. In developing a Budget Resolution, the Congressional budget committees provide a total allocation for all appropriations to the appropriations committees. The full Committee then determines suballocations for each of its subcommittees, who then have targets constraining their actions and recommendations.

With respect to the Reclamation Grants, the award of a grant is a Federal obligation. OSMRE has an excellent capability to obligate grant funds. In Fiscal Year 1985, the percentage of funds obligated was over 97 percent. However, there is also a figure called the "obligated balance". This measures how much of the obligations are actually being paid. For salaries, the time between obligation (when the salary is owed) and outlay (when the Treasury has to pay the cash) is usually short. Consequently, the amount of the obligated balance is usually also small.

However, for the AMRF, at the end of Fiscal Year 1985, the level of the obligated balance had grown to nearly \$552 million. One can interpret this figure as an indication that considerable grant funds have been awarded but have not yet been outlaid, i.e., spent. If users have not spent the funds, it implies to many analysts and decision makers that the "need" or "capability" has been overestimated. This is the major concern with respect to the level of funding for the State Reclamation Grants.

Perhaps, there is another measure for need or capability. However, "commitment" will not suffice because it does not generally denote a binding agreement on the parties involved. Although it may be additional information, this does not provide a new measure for obligation. Funds could still be awarded or obligated and would not be outlaid within a reasonable time. If it takes several years for the outlay to occur, appropriation committees may take the view that this budget authority could have been used more effectively elsewhere. After the cause of the delay is eliminated or past, the agency will be ready to obligate and outlay the funds.

In conclusion, although the actual coal fee receipts remain in the AMRF until Congress appropriates their use, the rate of availability will continue to depend upon the States' efforts to demonstrate need or their capability to use the funding, or both. OSMRE is working with the States to identify better measures of need or use. The States' obligation is more closely correlated with the timing of the use of the funds than OSMRE's obligation. This makes States' obligation more acceptable as an indicator to other interests such as OMB and the appropriations subcommittees. The agency has been sharing these data with the appropriations subcommittees. After the first two quarters of 1986, it appeared that the States' use of these funds was increasing; however, the third quarter data, in most cases, were quite disappointing

because the trend was reversed. In this quarter, the cumulative construction obligations declined to approximately \$11 million which is only 20 percent of the projection for that period.

We have to demonstrate to decision makers that the grant funds will be used quickly. Until the obligated balance begins to decline, analysts are drawing the impression that the grant funds are awarded and then sitting idle for several years. Knowing what the analysts look at should help in bringing information to their attention that portrays the true picture of need for AMRF grants and the true picture of the States' capabilities to use those grants. Actually doing so is a major challenge facing the States.

AMELIORATING THE ADVERSE CHEMICAL AND PHYSICAL PROPERTIES OF BENTONITIC CLAYS

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Abstract

Abandoned bentonite mines in the Black Hills of Wyoming are extremely difficult to reclaim due to the saline-sodic hazard and the high percentages of expanding clays. These clay spoils readily disperse upon wetting resulting in limited water infiltration, surface crusts detrimental to germination, and soluble salts that limit plant uptake functions. Reclamation of bentonite spoils calls for a two-step process to alleviate the adverse physical and chemical problems. Woodchips are applied at 20 tons per acre which breaks the surface crust allowing infiltration and leaching of the soluble salts. A calcium amendment is applied, (either lime, gypsum plus calcium chloride or phosphogypsum) to react chemically thus replacing and leaching sodium out of the root zone. The combination of amendments, physical manipulations to the seedbed, and the use of salt-tolerant grasses and shrubs results in effective reclamation for the Wyoming Abandoned Mine Lands Program.

INTRODUCTION

The original intent in establishing Title IV of the Surface Mine Control and Reclamation Act was to reclaim lands which were mined for coal and abandoned inadequately such that they pose a public safety hazard or are degrading the environment. The law was amended through the efforts of the western states and the Wyoming Congressional Delegation to allow non-coal abandoned mine sites to be reclaimed. Expanding the law to cover reclamation of non-coal sites has significant meaning for Wyoming where the bulk of abandoned mines are the result of mining to obtain minerals other than coal.

Most of this disturbance in the state of Wyoming is the result of orphan bentonite mines. Approximately 15,000 acres in the state are currently projected for reclamation under the abandoned mine lands program. This includes the Big Horn Basin, the Kaycee area and ongoing projects in the Black Hills of Crook and Weston Counties which is the subject of this paper. Bentonite mining is still very significant in this region. In fact it has been projected that Wyoming, Montana, and South Dakota contain 90% to 95% of the world's mineable bentonite deposits, of which over 200,000 acres of active bentonite mines are under permit in the state of Wyoming (Romo 1981).

Wyoming bentonite is classified as a swelling, montmorillonite clay exhibiting a two-to-one lattice and a sodium-dominated structure. Bentonite has been referred to as the "clay of 1000 uses" due to its ability to absorb 10-times its weight and 16-times its volume in water (Romo 1981). Its principle use is a

binding agent for pelletizing iron ore and as a lubricant for drilling exploration. Other diverse and unique uses include toothpaste additive, a filler for ice cream, and as a purifier in wine.

· MINING METHODS AND PROJECT AREA DESCRIPTION

Due to the diverse number of uses, mining companies must meet a number of grades which means opening a number of pits in various locations within a bed. In addition the clay is often exposed near the surface. Profitable mining for bentonite does not exceed an overburden to bentonite ratio of 10:1 (Hemmer and Beck 1977).

This type of haphazard mining operation results in surface disturbances ranging from 3 to 500 acres scattered throughout a 450-square-mile area in the Black Hills alone. Approximately 9,500 acres in the Black Hills will be under construction under the AML program. The reclamation area can be divided into two major projects based on past mining activities and geographical areas. They include the Southern Black Hills Project near the Upton-Clay Spur region and the Northern Black Hills Project. Habitat near Upton, Wyoming is dominated by big sagebrush-grassland and ponderosa pine vegetation types with lesser amounts of pine-juniper and riparian wetland. Average annual precipitation for the Upton project area is approximately 14 inches.

The second major project is located in the extreme northeast corner of the state near Colony, Wyoming. The project area is located primarily in a pine-scrub oak vegetation type with smaller communities of riparian/wetland, hay meadows and upland grassland habitat. Average annual precipitation for the Colony project area is 17 inches.

GEOLOGY

Seventy-five million years ago the Black Hills were covered by a shallow brackish sea. Volcanic eruptions resulted in ash deposits of which the montmorillonite clay bentonite was altered and formed (Smith 1984). Geologically the project can be separated into four distinct beds. They include the Newcastle Sandstone, the Mowry Shale, the Clay Spur or bentonite bed, and the Belle Fourche Shale.

Newcastle Bed

- It is the lowest formation, consisting of sandstone and sandy shales.
- It is a coarse material, acceptable as a plant growth medium.

The Newcastle sandstone is readily available as a topsoil borrow material source. Where used to cover saline-sodic spoils, it is recommended that 12 to 18 inches of this material be used to prevent the upward migration of sodium.

Mowry Pit Floor

- Comprises the formation directly below the bentonite bed.
- It is consistently acid in reaction, with a mean pH value of 5.0.

- Clay contents average 24% indicating a low amount of expanding clays.

There is a low content of soluble sodium (averaging 0.9) indicating a low potential for upward sodium migration. Observation of Mawry Pit Bottoms show that it does support vegetation where weathered. Therefore the concerns are the physical properties (the coarse, unfragmented shales on unweathered sites) and the acidic nature of the soil (Almas et al. 1986). Reclamation calls for either covering the pit bottoms, mechanically breaking or deep ripping unweathered shales and amending with lime.

Belle Fourche Shale

- Is directly above the bentonite bed and accounts for most of the spoil material encountered in the project areas. Belle Fourche spoil material is the least desirable as a plant growth medium.

Saturation percentages are commonly 100 to 200% indicating a high amount of expanding clays. Sodium Adsorption Ratios and Exchangeable Sodium Percentages are commonly over 30 indicating a very high saline-sodic hazard in Belle Fourche spoils. Saline-sodic conditions and high percentages of expanding clays make revegetation of abandoned bentonite mines extremely difficult. High soluble salt concentrations found in bentonite spoils increase the osmotic stress on plants. When water contacts bentonite the clay swells to form an impervious seal resulting in limited water infiltration and very poor aeration (Schuman and Sedbrook 1984).

OBSERVATIONS

Field trail research in Upton beginning in 1978 and again in 1981 by the State of Wyoming and the USDA High Plains Agricultural Research Station was initiated to determine if wood residue enhances reclamation of bentonitic spoil and to find a use for excess wood waste.

The first trial showed that grass production exceeded 1,000 lbs/acre compared to control plots which averaged only 16 lbs/acre (Schuman and Sedbrook 1984). The second trial by Smith et al. (1984, 1985) addressed the specific amount of wood residue and fertilizer necessary to reclaim bentonite spoils. Wood was applied at rates of 0, 20, 40 and 60 tons/acre and incorporated 12 inches into the spoil. Nitrogen was applied at rates of 0, 5, 10 and 15 lbs of available nitrogen per ton of wood. The results indicate that: 1) wood is effective in establishing plant growth; 2) grass production increases with increasing wood residue rates; 3) electrical conductivities decreases year-to-year under normal precipitation, and 4) wood increases soil moisture and soil infiltration (Belden 1986; Smith et al. 1984, 1985). This increase in water infiltration resulted in leaching of soluble salts from the surface down to a depth of 6 inches. However, the sodium has become greater relative to other salts in the system. Therefore, woodchips do not alleviate the sodium problem and the data indicates that a calcium amendment should be applied with wood to prevent the increase in the Sodium Adsorption Ratios. Reclamation of sodic soils require water to pass through the system to carry divalent ions (usually calcium) to react chemically, replacing exchangeable sodium on the colloid, thus flushing sodium out of the root zone. Research indicates that calcium chloride is the most effective chemical amendment for

sodic soils but is discounted for large-scale reclamation due to its high cost (Dollhopf et al. 1985; Jurinak and Wagenet 1982; Prather et al. 1978).

Research conducted by Montana State University near the Colony project area in South Dakota was initiated to determine effective chemical amendments for Belle Fourche spoils (Dollhopf et al. 1977). Observation here five years later and other research indicates that a combination of 75% gypsum plus 25% calcium chloride is only slightly less effective than calcium chloride alone and results in excellent plant establishment (Dollhopf et al. 1985; Jurinak and Wagenet 1982; Prather et al. 1978). CaCl_2 results in an immediate reaction with sodium due to its high solubility rate. Gypsum, although less soluble, seems to be more effective at the surface and provides a long-term source of calcium. Therefore, a combination of chemicals maximizes amendment potential while minimizing costs.

Also studied at the Montana State University plots was a combination of sulfuric acid and gypsum. However, this is not being used in our reclamation efforts primarily because of contractor handling problems. Other amendments worthy of attention include phosphogypsum which is a by-product of the phosphate mining industry. Phosphogypsum is similar in characteristics to gypsum but provides a ten-fold higher dissolution rate than gypsum. Limited data has indicated that phosphogypsum is effective in maintaining high infiltration in sodic soils (Gal et al. 1984; Kazman et al. 1983).

RECLAMATION

Considering the investigations and research conducted in the project areas, the Wyoming Abandoned Mine Reclamation process is as follows.

First identify unsuitable material, such as cleanings which are a low grade bentonite left on the surface and identified by their popcorn-like appearance. Cleanings are specially handled as a first operation and buried under 2 feet of cover.

Following grading and contouring, sampling after regrading occurs to determine chemical amendment rates. Samples are identified for clay content, pH, Sodium Adsorption Ratios and Cation Exchange Capacity relationships of the spoil.

Next a chemical amendment is applied. Apply lime if the pH is below 6. If the pH of the spoil is above 6 apply phosphogypsum or the combination 25% CaCl_2 plus 75% gypsum.

Following chemical amendments incorporate 20 tons of wood residue to an 8-inch-depth. Many of our contracts discriminate against sawdust but rather size woodchips to a minimum 2 inches in diameter. This will reduce the compactibility of the spoil and resist rapid decomposition. Nitrogen fertilizer is applied at 10 lbs of available nitrogen per ton of wood residue or 200 lbs/acre of nitrogen and phosphorus is applied at 20 to 40 lbs/acre.

Physical manipulation and revegetation practices that prove successful on clay spoils include pitting which is being used on over half of the project areas. One particular implement that deserves merit is the Dammer Diker. Seed is pneumatically broadcast on both sides of the machine resulting in effective

burial of the seed. Paddle-wheels are off-set resulting in staggered rows and thus effective erosion control. In the Dammer Dike case, pits are specified at 8-inches-deep and 8-inches-wide, which is smaller than conventional pits known in the northern Great Plains such as the Hodder Gouger. These pits have been observed to contain the 25-year-storm resulting in maximum water retention.

Species selected for revegetation should be adapted to clay textures, arid conditions, and salt tolerance. Grass species should be rhizomatous to be able to withstand the shrink-swell characteristics of the spoil. Species such as western wheatgrass, thickspike wheatgrass, streambank wheatgrass, or tall wheatgrass deserve merit as well as salt-tolerant shrubs such as four-wing saltbush or gardener's saltbush.

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RECENT DEVELOPMENTS AND CURRENT LEGAL AML ISSUES

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State of Tennessee v. Donald P. Hodel et al., U.S.D.C. M.D. Tenn. No. 3-86-0413. The State of Tennessee repealed its surface mining law and dissolved its regulatory program. The Director of OSMRE moved to suspend the State's AML program pursuant to section 405(c) of SMCRA. Tennessee filed suit claiming that OSMRE failed to effectively suspend the AML program and, therefore, cannot withhold AML monies from the State's AML program. Tennessee also claimed that the OSMRE had acted arbitrarily in not granting money to the state from the Secretary's discretionary share. Tennessee seeks a return to the state of AML funds that OSMRE withheld after it suspended the regulatory program. OSMRE has filed a motion to dismiss on the grounds that section 405(c) of the Act prevents the Secretary from funding a state program if the regulatory program has been withdrawn or suspended, and that the Secretary did not abuse his discretion by not funding a federal program in Tennessee.

Lucille A. White v. United States of America, Department of Interior, U.S.D.C. M.D. Penn. No. 83-1360. Plaintiff is the wife of an employee of contractor hired for AML project. The deceased was operating crane attempting to break up concrete cap on an abandoned shaft. The surrounding soil gave way and the crane fell into the shaft killing the operator. Plaintiff alleges that the Department of Interior failed to disclose dangerous condition of the area and that the Department was negligent in planning and executing the project. The court held that the claims were all barred by the discretionary function exemption of the Federal Tort Claims Act. The court reasoned that the decisions concerning safe execution of a project are discretionary, therefore, within the exemption, and that the decision to make information available to contractors rather than giving the information directly to the contractors is a policy decision and discretionary under the discretionary function exemption.

Drummond Coal Company v. Hodel, No. 85-5827 (D.C. Cir. 1986). The appellate court affirmed the district court's decision upholding the Secretary's abandoned mine land reclamation fee assessment regulations. The court rejected Drummond's challenge to the Secretary's assessment of the reclamation fee on that portion of the weight of coal which includes "impurities", such as water and debris not removed prior to the first sale, transfer of ownership, or use by the operator. The Court found the Secretary's regulations a reasonable interpretation of the Act.

AML-Superfund Issues, The Environmental Protection Agency (EPA) and OSM have discussed the possible overlap of missions and possible coordination on clean-up of non-coal sites. The Office of Management and Budget has proposed using AML fees to clean-up non-coal waste sites. EPA is constrained to impose certain reclamation standards on all sites. AML funds have no such restraints and there is no basis in the Act for imposing them. The

Department of Interior is preparing to negotiate a memorandum of understanding with EPA to address these issues. (Note-proper AML grant administration may require coordination with EPA, thus imposition of standards on these sites).

AML Grant as Income--Paul Berridge of Ohio received a grant from the State abandoned mine program to reclaim parts of his own property. Berridge used the grant to buy equipment and do the reclamation himself. Berridge retained the equipment and undertook other reclamation projects not on his own land. The Internal Revenue Service (IRS) later audited Berridge and recorded a tax deficiency for the year Berridge received the reclamation money. This has raised some concerns about whether all AML work done for a landowner will be characterized as income to the extent of the money spent.

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Rocky Mountain Mapping
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